WRD Resource Room Copy #1 EVER

REPORT TO THE SUPERINTENDENT

THE RESPONSE OF THE EVERGLADES MARSH TO INCREASED NITROGEN AND PHOSPHORUS LOADING

Part I: Nutrient Dosing, Water Chemistry, and Periphyton Productivity

Mark D. Flora[1], David R. Walker[2], Daniel J. Scheidt[3],
Ramona G. Rice[4], and Dixon H. Landers[5]

Please do not remove
this item from
Resource Room

OCTOBER 1988

Everglades National Park, Homestead, FL 33030

---

[1] National Park Service, Water Resources Division, 301 S. Howes Street, Room 335, Fort Collins, Colorado 80521

[2] Formerly with National Park Service, currently with St. Johns River Water Management District, Palatka, Florida 32078

[3] National Park Service, South Florida Research Center, Everglades National Park, Homestead, Florida 33030

[4] Drinking Water Research Center, Florida International University, Miami, Florida 33199

[5] U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon 97333

NATIONAL PARK SERVICE
Water Resources Division
Fort Collins, Colorado
Resource Room Property

TABLE OF CONTENTS

Page

TABLE OF CONTENTS i

LIST OF FIGURES ii

LIST OF TABLES iv

EXECUTIVE SUMMARY v

ACKNOWLEDGEMENTS vii

INTRODUCTION 1

EXPERIMENTAL DESIGN 8

METHODS 10

HYDROLOGICAL BACKGROUND 18

EXPERIMENT 1 RESULTS 21

- Water Chemistry 23
- Periphyton Biomass and Primary Production 23

EXPERIMENT 2 RESULTS 32

- Water Chemistry 41
- Periphyton Biomass and Primary Production 48

DISCUSSION 54

CONCLUSIONS 57

LITERATURE CITED 58

LIST OF FIGURES

Figure		Page
1	Map of south Florida	2
2	Map of Shark River Slough	3
3	Experimental design for field apparatus	9
4	Periods of nutrient addition into experimental channels	11
5	Periphytometer design: floating redwood frame holding racks of glass slides with enlarged view of a rack of 8 microscopic slides	16
6	Flowchart of periphyton primary production and biomass determination	17
7	Mean surface water discharge from the S-12 structures, monthly rainfall into the Shark River Slough, and mean water depth at Station P-33 (April 1983 - September 1984)	19
8	Background climatic and hydrological conditions at the Shark River Slough nutrient uptake study site (Water depth is daily mean value; water temperature and specific conductance are daily maximum values.)	20
9	Six week mean dissolved nitrate and dissolved orthophosphate addition to experimental channel B	22
10	Discharge in experimental channel B	24
11	Six week mean dissolved orthophosphate concentration (all sites) in experimental channel B	25
12	Six week mean dissolved nitrate concentration (all sites) in experimental channel B	26
13	Mean concentration (by site) within experimental channel B and controls for dissolved orthophosphate (n=27) and total phosphorus (n=13) (May 1983 - September 1984)	27
14	Mean concentration (by site, n=13) within experimental channel B and controls for ammonia, nitrate, organic nitrogen, and total nitrogen (June 1983 - September 1984)	28
15	Change in dissolved orthophosphate concentration with distance in experimental channel B (April 1983 - September 1984)	30
16	Change in dissolved nitrate concentration with distance in experimental channel B (April 1983 - September 1984)	31
17	Chlorophyll *a* concentrations from periphytometers at control sites and five locations in experimental channel B	33

Figure		Page
18	Periphyton dry weight from periphytometers at control sites and five locations in experimental channel B	34
19	Primary production of periphyton at control sites and five downstream locations in experimental channel B	36
20	Summary of primary production and biomass data for experimental channel B (April 1983 - September 1984)	37
21	Six week mean dissolved orthophosphate addition to experimental channel A and dissolved nitrate addition to experimental channel C	39
22	Discharge in experimental channel A and experimental channel C	40
23	Six week mean dissolved orthophosphate (PO_4-P) concentrations (all sites) in experimental channel A	42
24	Six week mean dissolved nitrate (NO_3-N) concentrations (all sites) in experimental channel C	43
25	Mean concentration (by site) within experimental channel A, experimental channel C, and the controls for dissolved orthophosphate (n=11) and dissolved nitrate (n=8) (October 1983 - September 1984)	44
26	Change in dissolved orthophosphate concentration with distance in experimental channel A (October 1983 - September 1984)	45
27	Change in dissolved nitrate concentration with distance in experimental channel C (October 1983 - September 1984)	46
28	Chlorophyll *a* concentrations from periphytometers in experimental channels A and C and at the control sites	49
29	Periphyton dry weight from periphytometers located in experimental channels A and C and at the control sites	50
30	Primary production of periphyton from periphytometers located in experimental channels A and C and at the control sites	51
31	Summary of mean primary production and biomass data for experiment 2 (October 1983 - September 1984)	52

Digitized by the Internet Archive
in 2012 with funding from
LYRASIS Members and Sloan Foundation

http://archive.org/details/reporttosuperint00flor

LIST OF TABLES

Table		Page
1	Field monitoring schedule for physical and chemical water quality parameters	12
2	Field monitoring schedule for biological parameters	13
3	Field equipment and water chemistry methods	14
4	Results of between-channel and within-channel analysis of variance (ANOVA) for experiment 1 water quality parameters	29
5	Results of between-channel and within-channel analysis of variance (ANOVA) for experiment 1 productivity and biomass parameters	35
6	Results of between-channel and among sites within a channel analysis of variance (ANOVA) for experiment 2 water quality parameters	47
7	Results of analysis of variance (ANOVA) between channels and among sites within a channel for experiment 2 biomass and primary production parameters	53

EXECUTIVE SUMMARY

While the consequences of increased nutrient loading are well documented for lakes, they are not well understood for flowing water systems, and are only vaguely understood in subtropical systems such as those found in the Everglades.

To assess the consequences of increased nutrient loading to the Shark River Slough in Everglades National Park, we implemented an 18-month experimental field study in which dissolved orthophosphate and dissolved nitrate were added to a wet prairie system in which the dominant macrophytes included *Eleocharis* spp. (spikerush) and *Utricularia* spp. (bladderwort). Objectives of this study included:

- assessing the effect of short-term increased nutrient loading on the water quality of the Shark River Slough, and
- determining the response of periphyton (attached algae) and macrophyte communities to increased nutrient loading.

By accomplishing these objectives, we are also able to assess the adequacy of the present water quality standards for delivery water to Everglades National Park, in protecting both the water quality and the natural biological communities of the Shark River Slough.

This report considers the consequences of increased nutrient loading upon nutrient uptake and changes in periphyton biomass and primary production. Subsequent reports assess the effects of increased nutrient loading upon macrophyte communities, bacteriological activity, and the response of periphyton community structure.

During the course of this study, a flow-through system was utilized in which three experimental channels, open at both ends and oriented to the direction of flow, were constructed within the Shark River Slough. Control sites were immediately adjacent to the experimental channels. Continuous nutrient additions were made at the upstream end (0 m) of the experimental channels and water chemistry analyses and biological determinations were undertaken at station locations 10 m, 20 m, 35 m, 65 m (channel B only), and 95 m downstream.

One experimental channel (B) received increased dissolved orthophosphate and dissolved nitrate loading from April 1983 through September 1984. The response of the system was both rapid and dramatic. Within six weeks of commencement of the nutrient addition, the indigenous periphyton mat community had disappeared; attached periphyton biomass growing on glass slide artifical substrates had increased more than 10-fold (relative to the control) and algal community structure had shifted. After several months of nutrient addition, qualitative changes in the macrophyte community were also apparent.

Two additional experiments were conducted from October 1983 through September 1984, in order to determine if dissolved orthophosphate or dissolved nitrate alone could induce the responses observed in experimenatl channel B. Only dissolved orthophosphate was added to experimental channel A and only dissolved nitrate was added to experimental channel C.

The response of experimental channel A was similar to that seen in experimental channel B. The periphyton mat dissipated soon after the beginning of dissolved orthophosphate introduction. In addition, increases in periphyton biomass and changes in periphyton community composition were noted. Changes in the macrophyte community also occurred.

The effects of adding only dissolved nitrate to experimental channel C were different from those noted in either experimental channels A or B. The periphyton mat dissipated, but only after eight months of dosing. Periphyton biomass grown on artificial substrates was less than at the control sites, which may indicate a slight periphyton growth inhibition in response to dissolve nitrate addition. A macrophyte community response also occurred with dissolved nitrate addition.

In summary, while the Shark River Slough has an ability to assimilate increased nutrient loading, even minor increases in dissolved orthophosphate loading can trigger major changes in periphyton and macrophyte biomass and community structure. Additionally, increases in dissolved nitrate may cause more subtle responses in periphyton and macrophyte biomass and community structure. These changes, in turn, may potentially alter higher levels of ecosystem organization.

ACKNOWLEDGEMENTS

The completion of an 18-month field project in a remote area of the Everglades required a tremendous amount of planning, logistics coordination, trial and error, and long hours in the field and laboratory. This could not have been completed without the cooperation and enthusiasm of a large number of people.

The authors would like to express their thanks to those people who contributed directly or indirectly to this process. Dr. Gary Hendrix and Dr. Peter Rosendahl were helpful and supportive in the conceptualization, implementation and review of this project. Michael Rikard, Raoul Rehrer, and Steve Gibbons offered considerable assistance in the construction of the field experimental channels. Orianna Roth, Ilsa Patton, Mike Graham, Peter Lorenzo, Kelly Norton, Bert Garcia, and Melissa Hamby put in long hours in both field sampling and laboratory analysis.

The authors would further like to acknowledge the technical assistance of Dr. John Makemson (Florida International University) who offered assistance in the primary productivity experiments, Dr. Bill Chang (University of Michigan) who completed the productivity calculations, and Mr. Don McKenzie (U.S. Geological Survey) who coordinated the U.S.G.S. water chemistry component. Finally, thanks are due to Steve Davis and David Swift (South Florida Water Management District), Dr. Ben McPherson (U.S. Geological Survey) and Joel Wagner (National Park Service) who reviewed the manuscript and offered helpful suggestions; Linda Jensen, Sandy Wittler, and Claudette Doffermyre who suffered through the typing of the various drafts with their usual patience and diligence and Hanae Akari, Kenneth Streeb, and Doris Rust who put in many hours completing the graphics with this report.

INTRODUCTION

Everglades National Park, located at the southern tip of Florida, encompasses approximately 5700 km^2, more than 90 percent of which is either permanently or seasonally inundated by water. A predominant feature of the Everglades wetland system is the freshwater slough, a shallow (less than 1.5 m deep), slowly flowing marsh system with seasonally fluctuating water levels and areas of inundation. The Shark River Slough (1000 km^2) is the largest freshwater flow system in Everglades National Park. It is the southernmost remnant of a much larger drainage system that once flowed unimpeded from the Kissimmee River drainage, through Lake Okeechobee, and then in a southwesterly direction across the southern one-third of Florida (Figs. 1 and 2).

Extensive manmade alterations to the natural flow pattern for the purposes of flood control, development, agriculture, and water storage have greatly altered the hydrologic regime north of Everglades National Park. The once unregulated, slow-moving sheetflow regime is now controlled by a complex system of levees, canals, water storage impoundments, pumping stations, and water control structures which influence both the quantity and quality of water entering the Shark River Slough.

Today, the areas south of Lake Okeechobee that once comprised the historical Everglades can be divided into three functional areas. The Everglades Agricultural Area (EAA) immediately south of Lake Okeechobee is a highly productive agricultural region of about 2800 km^2. Approximately 75 percent of this area has been developed for agricultural purposes supporting three principal uses: sugar cane (45 percent), pasture (20 percent), and vegetable crops (10 percent). Most of the remaining 25 percent is undeveloped, with less than five percent consisting of the urban areas of Clewiston, South Bay, and Belle Glade (Dickson et al., 1978).

The five Water Conservation Areas of the South Florida Water Management District (SFWMD), located south of the Everglades Agricultural Area, constitute the second functional area (Figure 1). These reservoirs consist of approximately 3500 km^2 of wetland that were once part of the historic Everglades. Today, a network of canals, levees, gates, and pumps encircles the system and allows the artificial manipulation of water levels throughout these areas for the purposes of flood control and water storage.

Everglades National Park, located south of the conservation areas, is the third functional area. Water Conservation Area 3A and its associated delivery canals form the northern boundary of the present day Shark River Slough and serve as the major source of surface water inflow into the slough (Figure 2).

Surface water nutrient concentrations as well as nutrient import and export budgets vary greatly from area to area, largely as a function of watershed usage. Nutrient concentrations in the waters of the intensively farmed Everglades Agricultural Area are high in both nitrogen and phosphorus constituents. Dickson, et al. (1978) and CH_2M HILL (1978) have both investigated water quality in the Everglades Agricultural Area.

CH_2M HILL, in a study for the Florida Sugar Cane League, monitored water quality adjacent to sugar cane plantations, vegetable farms, and cattle ranches in the Everglades Agricultural Area from July 1976 to September 1977 (CH_2M HILL, 1978). Mean concentrations of soluble phosphorus in backpumped water were found to be 70 $\mu g\ L^{-1}$ at sugarcane sites, 355 $\mu g\ L^{-1}$ adjacent to vegetable farms, and 122 $\mu g\ L^{-1}$ near cattle ranches. Combined nitrate

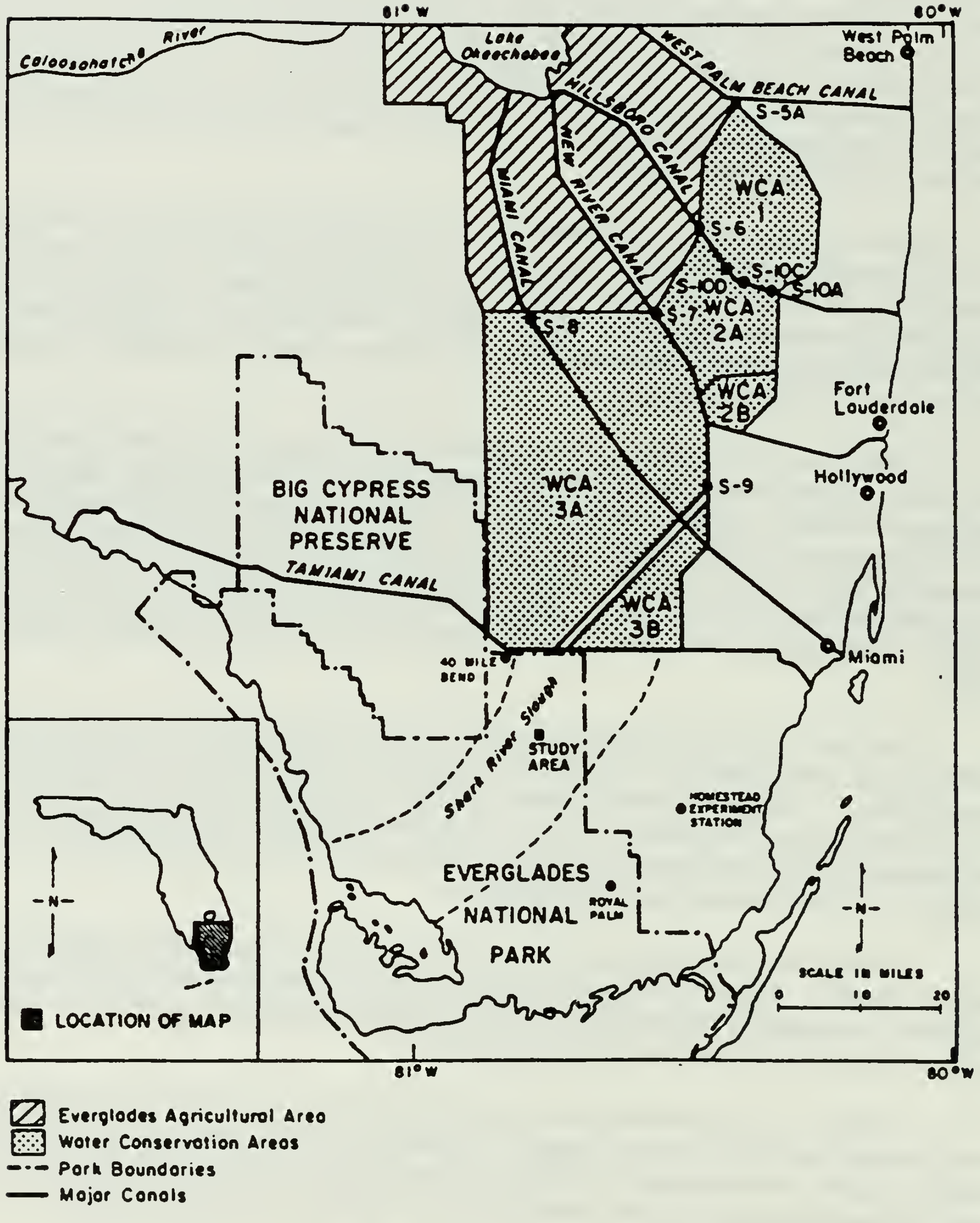


Figure 1. Map of south Florida.

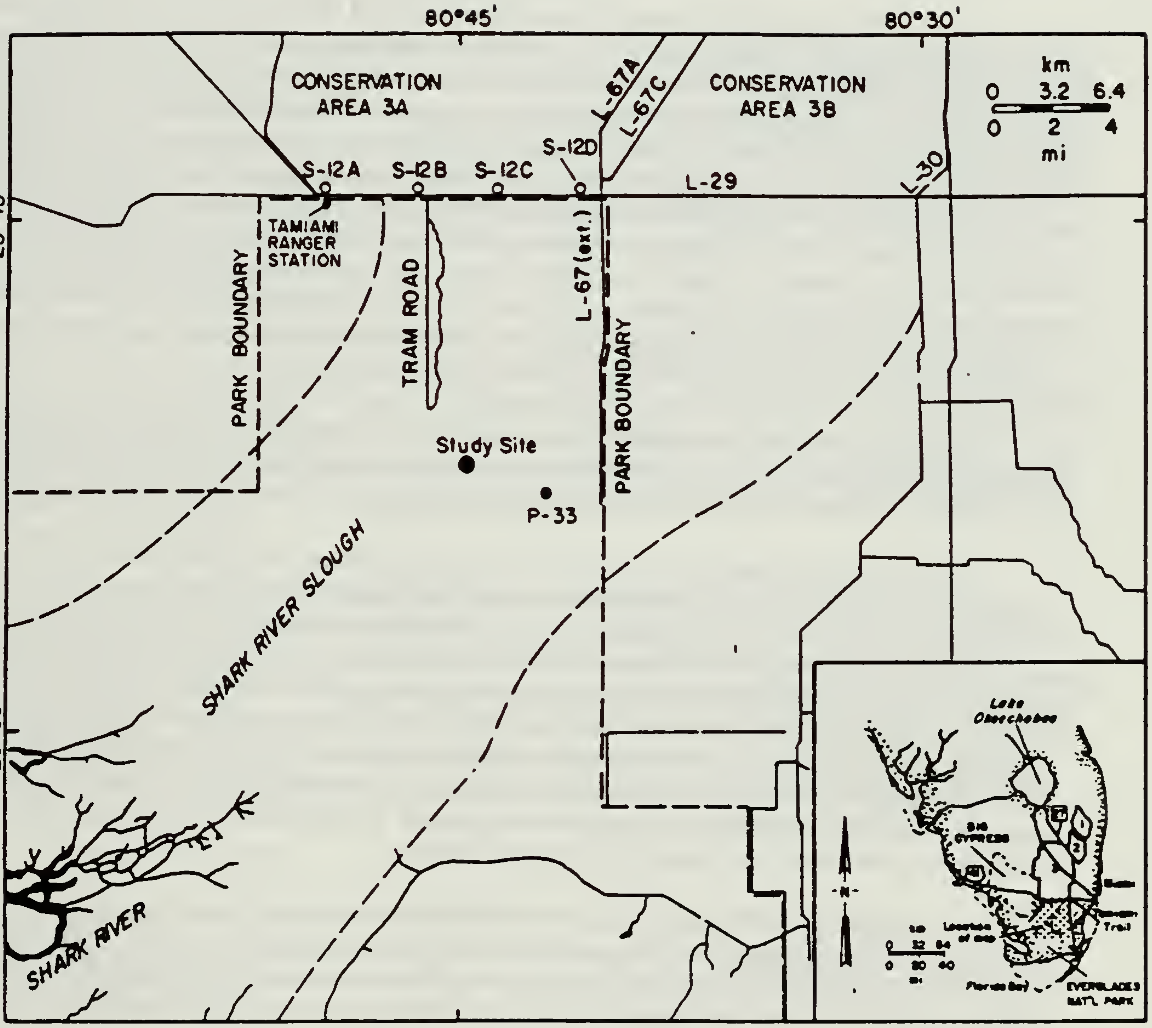


Figure 2. Map of Shark River Slough.

(NO_3) and nitrite (NO_2) concentrations were similarly high. Mean nitrate + nitrite concentrations were 2720 µg L^{-1} at sugarcane sites, 1050 µg L^{-1} adjacent to vegetable farms, and 1270 µg L^{-1} near cattle ranches.

Dickson, et al. (1978) evaluated water quality data relating to various agricultural types and found when data were grouped by canal and the results were evaluated on a seasonal basis, an integrated effect of agriculture on water quality in the canals of the Everglades Agricultural Area was evident. Phosphorus, nitrite, and ammonia concentrations were generally higher and dissolved oxygen concentrations generally lower during the wet season when pumping from the farms was most evident.

Lutz (1977) found that water discharged through the four major pumping stations from the Everglades Agricultural Area to the northern Everglades exerts a major influence on the water quality in the Water Conservation Areas. Lutz (1977) reported that the S-5A, S-6, S-7, and S-8 pump stations contribute roughly 90 percent of the nitrogen and 76 percent of the phosphorus introduced to the Water Conservation Areas via surface water inflows, although these pump stations contribute only 49 percent of the surface water. Data available from the South Florida Water Management District (1978-82) for pump stations S-7 and S-8, located at the southern end of the Everglades Agricultural Area, also indicate high nutrient concentrations in water pumped southward from the Everglades Agricultural Area. Mean nitrate concentrations are reported to be 938 µg L^{-1} (as N) and 806 µg L^{-1} (as N) at S-8 and S-7, respectively. Mean orthophosphate phosphorus concentrations are reported to be 42 µg L^{-1} (as P) at S-8 and 53 µg L^{-1} (as P) at S-7 (Mattraw et al., 1987).

Small amounts of sporadic water quality data from various areas of the Everglades are available as early as the 1940's; however, comprehensive water quality studies addressing the Water Conservation Areas north of Everglades National Park are not available until the 1970's.

The first systematic collection of nutrient data from the area south of Lake Okeechobee was begun by the U.S. Geological Survey in 1970 (Freiberger 1972, Miller 1975). Nine surveys (one wet season and one dry season each year) were completed from September 1970 through April 1975 during which determinations were made for soluble reactive phosphorus (PO_4-P), ammonia nitrogen (NH_3-N), nitrite nitrogen (NO_2-N), and nitrate nitrogen (NO_3-N). Generally, nutrient concentrations were found to be higher in the areas influenced by development than in the undeveloped areas of the Water Conservation Areas, Big Cypress, and Everglades National Park. However, since only two surveys were completed each year and the hydrolgoical conditions varied considerably from year to year, it is not possible to use this data in an analysis of either areal or temporal nutrient trends.

McPherson (1973) found that concentrations of inorganic and organic nitrogen compounds and phosphorus compounds increased in Water Conservation Area 3A during the drought conditions that ended in June 1971. These increases are probably more related to evapotranspiration and the concentration of wildlife in water filled depressions than to any other factor.

Gleason (1974), in a comprehensive study in Water Conservation Area 2A, noted the effect of marsh vegetation on water quality. Through this study it was found that marsh vegetation absorbed much of the relatively high nutrient inputs introduced from canal inflows. Dissolved inorganic nitrogen compounds and dissolved phosphate phosphorus were considerably lower in the marsh than in canal inflows even though sodium, chloride, and silica differed very little between the marsh and the canal. Additionally, dissolved organic nitrogen and dissolved organic phosphorus concentrations did not vary significantly between canal and marsh, suggesting that they are not available for plant uptake.

Waller and Earle (1975) completed a comprehensive report on the chemical and biological quality of water in the Everglades system that was based upon data collected by the U.S. Geological Survey from October 1972 to April 1974. The results of this study show generally poor water quality in water that is discharged from the Everglades Agricultural Area. The high nutrient concentrations at these inflow points are attributed to both the highly organic nature of the soils and the buildup of years of fertilizer use. The authors further report improving water quality as the water flows south and east. The decrease in nutrient concentration is thought to occur as these constituents are assimilated by plants, sorbed onto organic materials and clay, or are entrapped by the sediments. Dilution caused by rainfall and concentration caused by evapotranspiration were also found to be important factors in influencing the quality of water (Waller and Earle, 1975).

McPherson et al. (1976) further evaluated the U.S. Geological Survey data base in order to make a qualitative assessment of the effects on water quality of backpumping water into the Water Conservation Areas. They observed that water quality in parts of the Everglades region had changed over the years and that increased concentrations of nutrients from agricultural and urban development influenced water quality at some locations. It was further suggested that increased nutrient loading could potentially change the Everglades environment by causing increased growth in aquatic plants, shifts in food web structure, and possibly even changes in animal populations.

Detailed nutrient inflow and outflow budgets for the Water Conservation Areas have been computed for the periods July 1972 through June 1973 by Waller (1975) and for the years 1978 through 1979 by Millar (1981). While the Waller study attributes a large amount of nutrient loading to inputs from precipitation, the type of bulk precipitation monitors in place during the time of the study have more recently been found to produce inaccurate data when used for nutrient assessment. Thus, the relative loadings presented may reflect inaccuracies due to collection methodology.

Millar (1981) found that the water quality in each of the Water Conservation Areas is largely a function of the land use of the drainage basins which flow into the area. Highest nutrient concentrations were found at those sites in close hydrological proximity to the Everglades Agricultural Area. Water quality generally improved as distance increased from the agricultural influences. The most impacted canal stations typically had mean total nitrogen concentrations of 4000-5320 $\mu g\ L^{-1}$ and total phosphorus concentrations of 70-123 $\mu g\ L^{-1}$. Canal stations on watersheds less influenced by agriculture or urban development typically reported total nitrogen concentrations of less than 2000 $\mu g\ L^{-1}$ and total phosphorus concentrations less than 12 $\mu g\ L^{-1}$.

Recent data (1978-83) from the South Florida Water Management District's water quality monitoring program further indicate that surface water drainage from the intensively cultivated Everglades Agricultural Area is the major source of both nitrogen and phosphorus loading to the northern Everglades south of Lake Okeechobee (Federico, in prep.).

Flora and Rosendahl (1982a) completed an analysis of 1972-1980 seasonal nutrient concentrations in the Shark River Slough. Marsh surface water nutrient concentrations were found to be low with total orthophosphorus concentrations generally less than 10 $\mu g\ L^{-1}$ (as P) and total phosphorus concentrations generally less than 20 $\mu g\ L^{-1}$ during the wet season. Marsh total nitrogen concentrations were moderate, ranging from 530 to 2310 $\mu g\ L^{-1}$. However, more than 90 percent of the total nitrogen consisted of the organic nitrogen fraction. Inorganic forms, including nitrate, nitrite and ammonia, which are more readily available for plant consumption, totalled less than 100 $\mu g\ L^{-1}$.

Everglades National Park contains a number of diverse wetland habitats ranging from shallow coastal marine environments to freshwater systems which include sawgrass marshes, wet prairies, slough communities, and tree island communities. The sawgrass (*Cladium* sp.) marshes represent the most common grouping, comprising more than 50 percent of the Everglades wetland area (Loveless, 1959). The other major grouping includes the wet prairie communities dominated by spikerush (*Eleocharis* sp.)/bladderwort (*Utricularia* spp.) assemblages. To a lesser extent, arrowhead (*Sagittaria* sp.), maidencane (*Panicum* spp.), and water hyssop (*Bacopa* spp.) occur in the wet prairies. Tree islands and sloughs make up the remainder of the wetlands.

Studies of the algal community structure, biomass, and production in the southern Everglades have previously been completed by Van Meter (1965), van Meter-Kasanof (1973), Wilson (1974), Wood and Maynard (1974), and Browder, et al. (1982).

The algal community of the southern Everglades marsh system is unusual. The algal community of the Shark River Slough is dominated by a diverse and seasonally massive community of calcareous periphyton, which may exist as either a benthic or floating algal mat or as algae attached to the stem of macrophytes (i.e., epiphytic). Van Meter-Kasanof (1973) reports an almost total absence of phytoplankton in the open marsh system of the southern Everglades.

The dominant periphyton associated with the *Eleocharis* sp./*Utricularia* spp. marsh of the Shark River Slough include calcareous blue-green algae and green algae. Van Meter-Kasanof (1973), in her study of the periphyton community structure in the Shark River Slough, found the most numerous genera of blue-green algae to include: *Scytonema*, *Lyngbya*, *Oscillatoria*, *Phormidium*, *Leptobasis*, *Microchaete*, *Plectonema*, and *Schizothrix* while the most numerous genera of green algae are represented by: *Penium*, *Oedogonium*, and *Spirogyra*.

Gleason and Spackman (1974) discuss the significance and importance of the calcereous blue-green algal periphyton to the marsh system of the Everglades. First, its areal extent is impressive, being found abundantly in all three of the Water Conservation Areas, Everglades National Park, Big Cypress National Preserve, and the inland prairies of the southeast coast. Secondly, the calcareous algal periphyton probably functions as a significant primary producer and an integral component of the food chain, and thirdly, the blue-green algae in the periphyton may be quantitatively significant sediment producers of the calcitic mud, which underlies the periphyton, and is the second most abundant sediment type found in the region.

It is well known that natural wetland systems have the capacity to act as "biological filters" in the removal of nutrients from water and wastewater (Steward and Ornes, 1975; Nichols, 1983). However, the assimilation of excessive nutrients is sometimes accompanied by changes in the natural communities, often favoring species more adept in competing in an enriched nutrient environment. Changes in species composition, biomass, and productivity of primary producers including the phytoplankton, the algal periphyton, and the macrophytes are often noted first, and may be accompanied by resultant alterations at higher levels of the food chain.

Ornes and Steward (1973) found that calcareous periphyton disappeared completely during enrichment studies of the Everglades marsh which utilized phosphorus introduction into field enclosures.

Swift (1981), in a study of periphyton growth rates, species composition, and community structure in the Water Conservation Areas, found that periphyton are very responsive to changes in water quality, especially enrichment by nitrogen and phosphorus nutrients. Excessive nitrogen and phosphorus enrichment caused a reduction in the number of nutrient sensitive algal species and an increase in the abundance of pollution tolerant species. Two filamentous blue-green algae (*Schizothrix calcicola* and *Scytonema hofmanni*) dominated the periphyton in interior areas of Water Conservation Areas 2A and 3A where nutrient concentrations were low; while periphyton at marsh sites adjacent to canals delivering nutrient enriched water from the S-10 structures were dominated by specialized nutrient tolerant algal species including the filamentous blue-green algae *Microcoleous lynbyaceous* and diatoms indicative of nutrient enrichment including *Gomphonema parvulum*, *Nitzschia amphibia*, *Navicula confervaceae*, and *Nitschia palea*. Marsh water phosphorus concentration was also found to be the major factor regulating periphyton growth rates in the Water Conservation Areas.

Continued water quality and biomonitoring studies conducted in Water Conservation Area 2A by Swift and Nicholas (1987) show that enriched nutrient concentrations penetrated deeper into the interior marsh during 1980-82, than was reported for 1978-79 (Swift, 1981). In addition, Swift and Nicholas (1987) reported that algal periphyton species diversity is reduced, and algal periphyton biomass is increased in areas of the Water Conservation Areas as a result of pumping nutrient enriched canal waters across the marsh.

Macrophyte biomass, community structure, and productivity may also be influenced by nutrient concentrations of the surrounding water. Studies by Steward and Ornes (1975) suggest that important submerged or floating leaved macroscopic plants such as *Chara* sp. and *Utricularia* spp. may be eliminated by nutrient enrichment because of either higher nutrient concentrations or reduced light penetration. Recent work by Davis (1988) indicates that cattails (*Typha* sp.) are replacing sawgrass in areas of the Water Conservation Areas that are receiving increased nutrient inflow.

These findings emphasize the important interrelationships between components of the marsh ecosystem. If the periphyton are eliminated or seriously altered, diurnal dissolved oxygen fluxes and marl deposition rates might be altered and changes in pH of the marsh waters might also occur. System-wide changes in basic water quality parameters are a major concern and could predictably influence other trophic levels of the ecosystem.

The resolution of water management issues in the Everglades system tends to be very complex. In the 1980's, two water resource issues have developed which could affect the quality of water delivered to Everglades National Park.

The first issue resulted from a severe rainfall deficiency which began in June 1980 and lasted into 1982. This drought created the lowest regional water storage levels recorded in southern Florida. The South Florida Water Management District proposed that canal water that was currently being lost to the ocean be backpumped (upgradient) into the Water Conservation Areas in order to enhance water supply (SFWMD, 1982). Four basins east of the Water Conservation Areas were selected. Although water quality was one criteria utilized in basin selection, several of the basins selected contained areas of low to medium density housing and agricultural activity, both of which can contribute to increased nutrient loading. Soon after the plan was adopted, the drought ended, eliminating the necessity for full plan implementation. However, the plan remains an alternative in future water shortage situations and the impacts of the plan on nutrient loading within the Everglades ecosystem are not understood.

The second issue has resulted from nutrient enrichment problems presently being encountered in Lake Okeechobee. Historically, much of the water utilized in sugar cane and vegetable agriculture in the Everglades Agricultural Area was backpumped into the lake as a conservation measure during the winter and spring dry seasons. The water that reentered the lake typically contained higher nutrient concentrations than when it had been released from the lake. Studies undertaken in the late 1970's indicated that Lake Okeechobee was becoming moderately eutrophic (Federico et al. 1981). Thus, in 1979 the South Florida Water Management District adopted the Interim Action Plan. This is a management strategy that calls for a minimizing of backpumping nutrient-rich water from the Everglades Agricultural Area north to the Lake. Out of concern for the increasingly eutrophic condition in Lake Okeechobee, nutrient-rich water from the Everglades Agricultural Area is kept out of the lake and sent south toward the Water Conservation Areas and Everglades National Park. The result has been that, in recent years, the Everglades system south of Lake Okeechobee has been subjected to greater nutrient loading than in the past, which has exacerbated biological changes due to higher nutrient concentrations (Scheidt et al. 1988).

Because of the potential for future nutrient loading increases into Everglades National Park, an 18-month field study was conducted by the National Park Service in order to better understand the impacts of increased nitrogen and phosphorus loading on the water quality, algae, and aquatic plant communities of the Shark River Slough.

The objectives of this study include:

- determining the impact on water quality of short-term increased nutrient loading to the Shark River Slough.

- determining the impact of increased dissolved nitrate and dissolved orthophosphate concentrations on periphyton and aquatic macrophyte biomass, primary productivity, and community structure.

Information gained in accomplishing these objectives will be useful in assessing the adequacy of the present delivery water quality standards in protecting the natural biological communities of the Shark River Slough, Everglades National Park.

EXPERIMENTAL DESIGN

As a result of potential adverse impacts of increased nutrient loading, a study was planned in which the effects of nutrient dosing on water quality and the periphyton and macrophyte communities could be assessed. Preliminary project planning showed that laboratory studies are not generally expected to approach the complexity of the natural system; and field experiments, such as enclosures and whole lake experiments, were not directly applicable to shallow slowly-flowing marsh ecosystems such as the Shark River Slough. Therefore, a flow-through system was adopted in which three experimental channels, open at both ends and oriented with the direction of flow, were constructed in the marsh to allow for controlled dosing in the Everglades sheet flow environment (Fig. 3). Each experimental channel measured 5 m by 100 m and was constructed of 1.5 mm fiberglass sheets successively overlapped and sunk 15 cm into the sediments.

Nutrient additions were made at the upstream end (0 m) of the experimental channels by means of a continuous-dosing Prominent^{R} pumping system that delivered measured concentrated nutrient solution from a 100 L reservoir into four delivery tubes (1.0 cm inner diameter) spaced approximately 1 m apart across each experimental channel. These pumps delivered a pulse of nutrients every few seconds, and were powered by 12 volt DC batteries. A series of vertical and horizontal water chemistry profiles indicated that the added nutrients were well mixed within 10 m downstream from the site of nutrient addition.

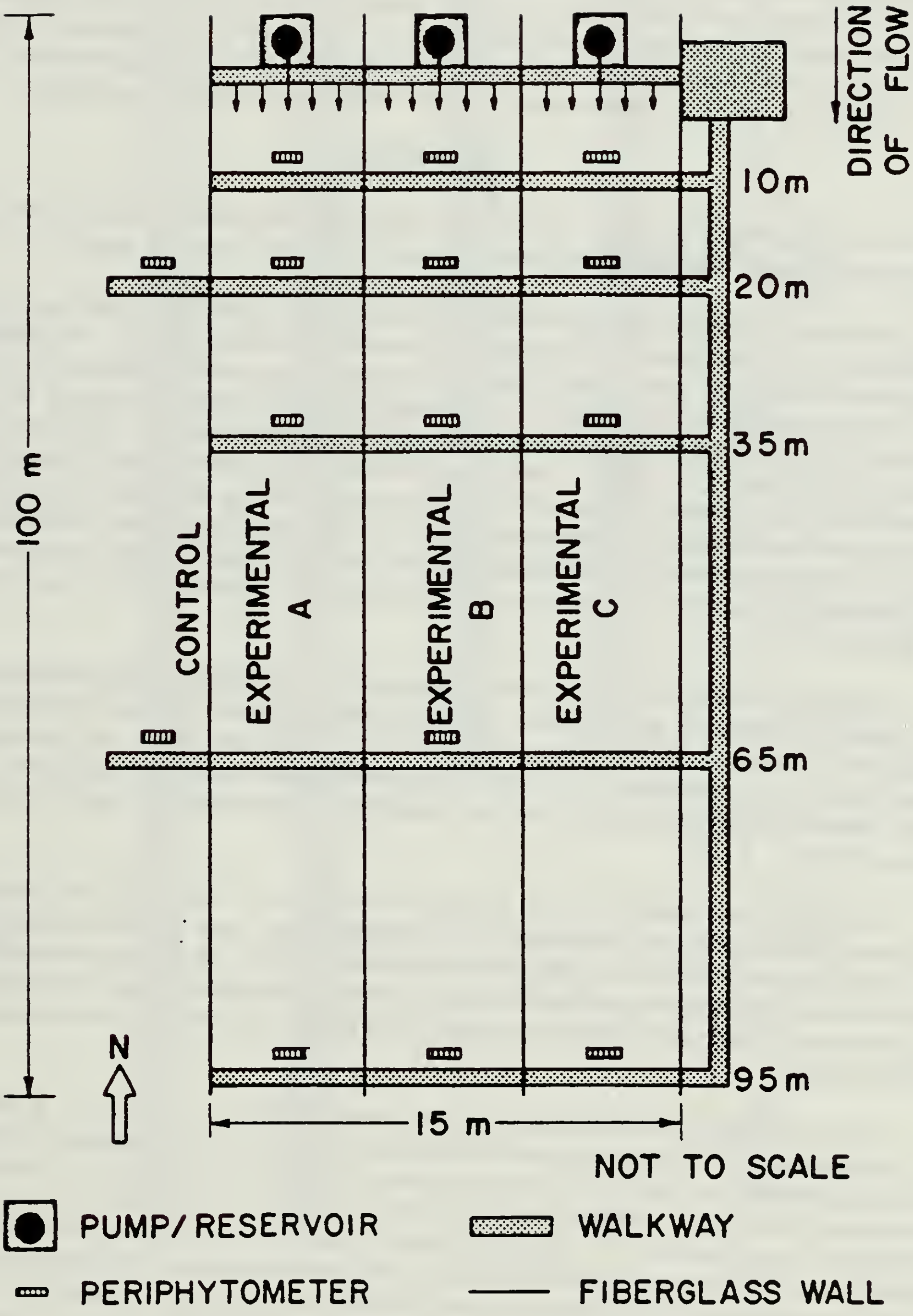


Figure 3. Experimental design for field apparatus.

Reagent-grade Mallinckrodt phosphoric acid (H_3PO_4) and food-grade Mallinckrodt sodium nitrate ($NaNO_3$) diluted to the desired concentration were used as the phosphate and nitrate sources, respectively. Nutrient addition of dissolved orthophosphate + dissolved nitrate into experimental channel B occurred from April 1983 to September 1984 (experiment 1). Addition of dissolved orthophosphate only into experimental channel A and dissolved nitrate only into experimental channel C took place from October 1983 to September 1984 (experiment 2). No nutrients were added to the control sites located adjacent to experimental channel A (Fig. 4). Thus, these control sites reflect natural background marsh conditions.

METHODS

The monitoring of physical, chemical, and biological parameters was conducted throughout the study. Sampling schedules are presented in Tables 1 and 2.

Parameters continuously monitored included water level, water temperature, specific conductance, and solar radiation utilizing instruments listed in Table 3. In addition, daily precipitation available at three local National Oceanographic and Atmospheric Administration (NOAA) meteorological stations (Royal Palm Ranger Station, Forty-Mile Bend, and the Homestead Experiment Station) (NOAA, 1983, 1984) were utilized in a Thiessen estimation of monthly rainfall (Lew et al., 1982). From April 1984 to September 1984, the rainfall station at the Homestead Experiment Station was out of service. During this time, the rainfall in the slough was estimated from the other two stations. Daily discharge data computed by the U.S. Geological Survey allowed for the quantification of surface water delivery into the Shark River Slough through the four S-12 control structures located approximately 15 km north of the study site (Fig. 2).

Discharge within the experimental channels was determined approximately every two weeks using Rhodamine^R dye studies. Dye was injected below the water surface and water was sampled 10 meters downstream every two minutes for one hour. A fluorometer was used to determine dye concentration in each sample, and time versus concentration curves were plotted. Water velocity was defined by the distance traveled and the time of peak concentration.

Discharge responded not only to stage but also to the extent of the periphyton mat and the species composition and biomass of the macrophytes. As a result of changes in periphyton and macrophyte biomass and community structure brought on by nutrient addition, it was not possible to establish stage-discharge rating curves in the experimental channels. Rather, it was necessary to interpolate daily discharge from stage data between successive time-of-travel determinations.

Water chemistry determinations in the experimental channels and at the control sites were completed by both the National Park Service and the U.S. Geological Survey according to methods presented in Table 3. A composite water sample was obtained at each sampling site by combining mid-depth subsamples collected at 1.25 m, 2.5 m, and 3.75 m across each channel site. Samples for U.S. Geological Survey analysis for dissolved nutrient constituents (dissolved orthophosphate-phosphorus, dissolved nitrate-nitrogen, dissolved nitrite-nitrogen, dissolved ammonia-nitrogen, and dissolved organic nitrogen) were filtered and fixed in the field and analyzed using standardized U.S. Geological Survey methods (USGS, 1979) by the USGS laboratory in Ocala, Florida. Nonfiltered samples were analyzed for total nitrogen and total phosphorus by the same laboratory. Due to the extremely low concentrations of dissolved orthophosphate and dissolved nitrate found in the natural slough waters, the National Park Service supplemented the water chemistry data supplied by the USGS with additional dissolved orthophosphate and dissolved nitrate determinations. The techniques were specifically modified for the determination of low dissolved orthophosphate and dissolved nitrate

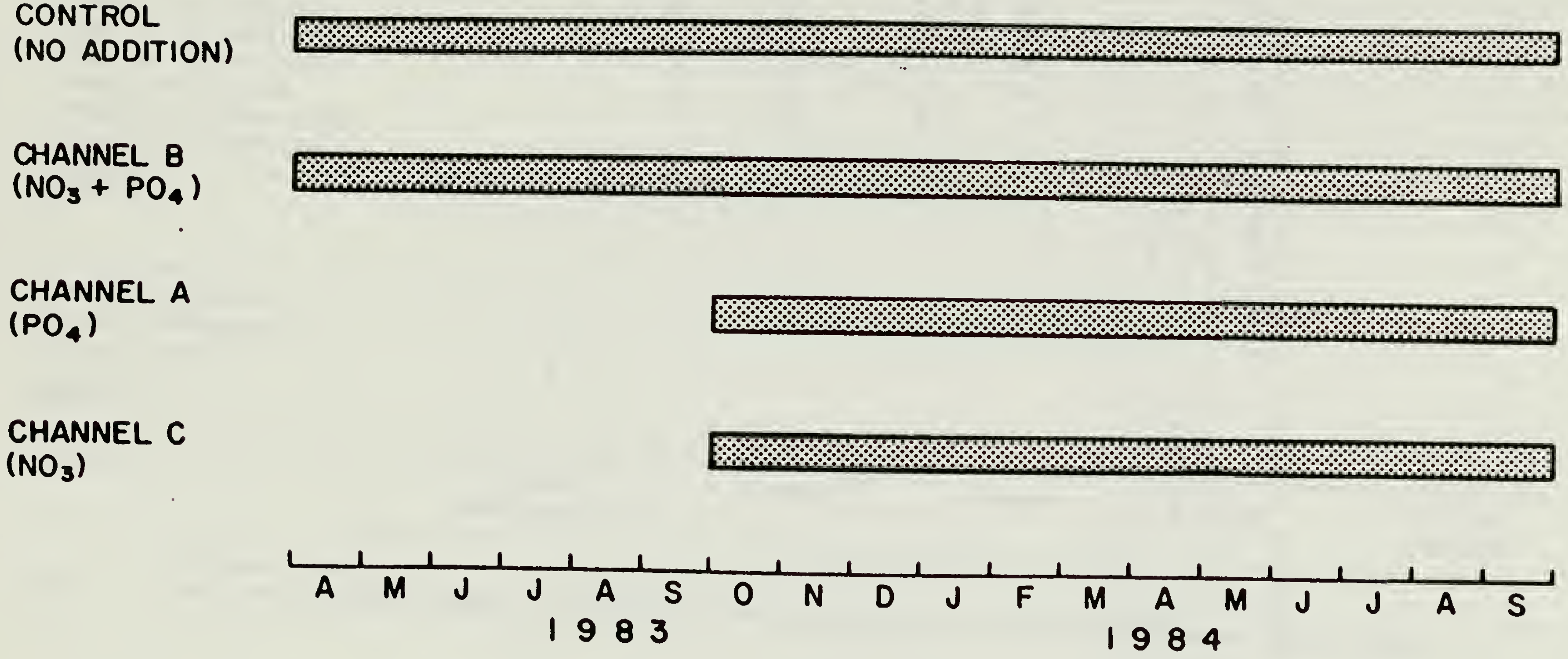


Figure 4. Periods of nutrient addition into experimental channels.

Table 1. Field monitoring schedule for physical and chemical water quality parameters (April 1983 - September 1984).

Parameter	Continuous or Daily	2 weeks	4 weeks	6 weeks	Special Studies
PHYSICAL					
water level	x				
water temperature	x				
solar radiation	x				
discharge		x			
CHEMICAL					
specific conductance	x				
phosphate (dissolved)		x			
total phosphorus			x		
nitrate (dissolved)			x		
nitrite (dissolved)			x		
ammonia (dissolved)			x		
organic nitrogen (dissolved)			x		
total nitrogen			x		
pH				x	
alkalinity				x	
diurnal dissolved oxygen					x
diurnal pH					x
diurnal water temperature					x

Table 2. Field monitoring schedule for biological parameters (April 1983 - September 1984).

Parameter	6 or 7 weeks	Pre/Post Experiment	Special Study
PERIPHYTON			
chlorophyll a	x		
dry weight	x		
^{14}carbon primary production	x		
community composition	x		
MACROPHYTES			
community composition		x	
chemical composition		x	
BACTERIOLOGICAL (Maltby, 1985)			
decomposition			x

Table 3. Field equipment and water chemistry methods.

Measurement	Method
PHYSICAL	
water level	Leupold and Stevens Type F Model 68 water level recorder
water temperature	Peabody-Ryan Model J recording thermograph Corning pH/temperature meter (Model 4)
solar radiation	Belfort 5-3850 recording pyranograph
discharge	Rhodamine dye flow tracer method using a Turner Associates Model 111 fluorometer
CHEMICAL	
specific conductance	Beckman RQ-4A portable conductivity recorder
pH	Corning pH/temp meter 4
dissolved oxygen	YSI Model 57 oxygen meter
phosphate-phosphorus	USGS, 1979 (parameter 00671)
phosphate-phosphorus (low level)	Strickland and Parsons, 1972
total phosphorus	USGS, 1979 (parameter 00665)
nitrate-nitrogen	USGS, 1979 (parameter 00618)
nitrate-nitrogen (low level)	Strickland and Parsons, 1972
nitrite-nitrogen	USGS, 1979 (parameter 00613)
ammonia-nitrogen	USGS, 1979 (parameter 00608)
organic nitrogen	USGS, 1979 (parameter 00607)
total nitrogen	USGS, 1979 (parameter 00625)
alkalinity	APHA, 1980

concentrations (Strickland and Parsons, 1972). Water utilized for these determinations was sampled and composited in the manner described previously. Samples were maintained in the dark at 4°C, filtered in the lab, and analyzed within six hours of sampling.

In addition to routine nutrient analyses, alkalinity, and pH were determined every six to seven weeks in conjunction with the biological sampling, and diurnal studies of dissolved oxygen, pH, and water temperature were conducted approximately monthly during the later stages of the study (Scheidt et al., 1985).

Determinations of periphyton community composition, biomass, and primary production were completed utilizing periphyton communities that were allowed to develop for six to seven weeks on vertical glass slide artificial substrates (2.5 cm by 7.5 cm) suspended approximately 5 cm below the water. The glass slides were mounted in redwood rack periphytometers* (Fig. 5) similar to those used to monitor periphyton in the Water Conservation Areas (Swift, 1981; Swift and Nicholas, 1987). Periphytometers were placed at five locations in experimental channel B (10 m, 20 m, 35 m, 65 m, 95 m) and four locations each in experimental channels A and C (10 m, 20 m, 35 m, 95 m). Two periphytometers were also located at the control sites (Fig. 3).

Periphyton communities colonizing the glass slides during the six to seven week period were analyzed for biomass and primary production. Samples were obtained by scraping the periphyton attached to the exposed surface (30.7 cm^2) of the glass slide into 5 ml screw cap vials. The vials were then injected with 0.5 ml of a 10 micro Curie ml^{-1} solution of labeled sodium bicarbonate (NaH $^{14}CO_3$) (New England Nuclear NEC-086S) and brought up to a 5 ml standardized volume using slough water from the sampling site filtered through a 1.2 micron glass fiber filter. Four vials were then incubated in situ for one hour, the incubations beginning at the first site at approximately 10 a.m. and at the last site at approximately noon. Because of the number of sites and replicates and the length of incubation, it was necessary to accomplish the ^{14}Carbon primary production determination over two consecutive days. Seven sites (10 m and 20 m) were sampled the first day, and eight sites (35 m, 65 m, and 95 m) were sampled the following day (Fig. 3). The date of the first pair of field days is reported. A pyranograph recorded solar radiation throughout the incubation period and sampling site water temperature, pH, and alkalinity were also measured.

Three vials at each periphytometer site served as light bottle replicates, while a fourth was utilized to provide the dark bottle correction. The reaction was stopped after one hour of incubation by immersing the vials in ice water and transferring them in the dark to the laboratory for homogenization and filtration according to methods modified from Brock and Brock (1967) and Brock (1970). Homogenization and filtration in the laboratory were generally completed within six hours of the field incubation.

Figure 6 presents a flowchart of the laboratory analysis procedure used in the determination of the periphyton primary production and biomass.

In order to determine primary production, a 0.5 ml subsample of the homogenate was filtered through a 0.45 micron Metricel^R (Gelman) membrane filter (25 mm). The membrane filters were then placed in scintillation vials and covered with 0.5 ml of 0.5 N HC1 in order to eliminate any residual ^{14}C bicarbonate activity (Lean and Burnison, 1979). After two hours, 10 ml of National Diagnostics Filtron X scintillation fluor was added to the scintillation vials which were then counted on a Beckman 9000 liquid scintillation counter. Determination of the

---

*The original design for the redwood rack periphytometer is from Mr. Jeff Goldstein, Department of Biology, Antioch College, Yellow Springs, Ohio.

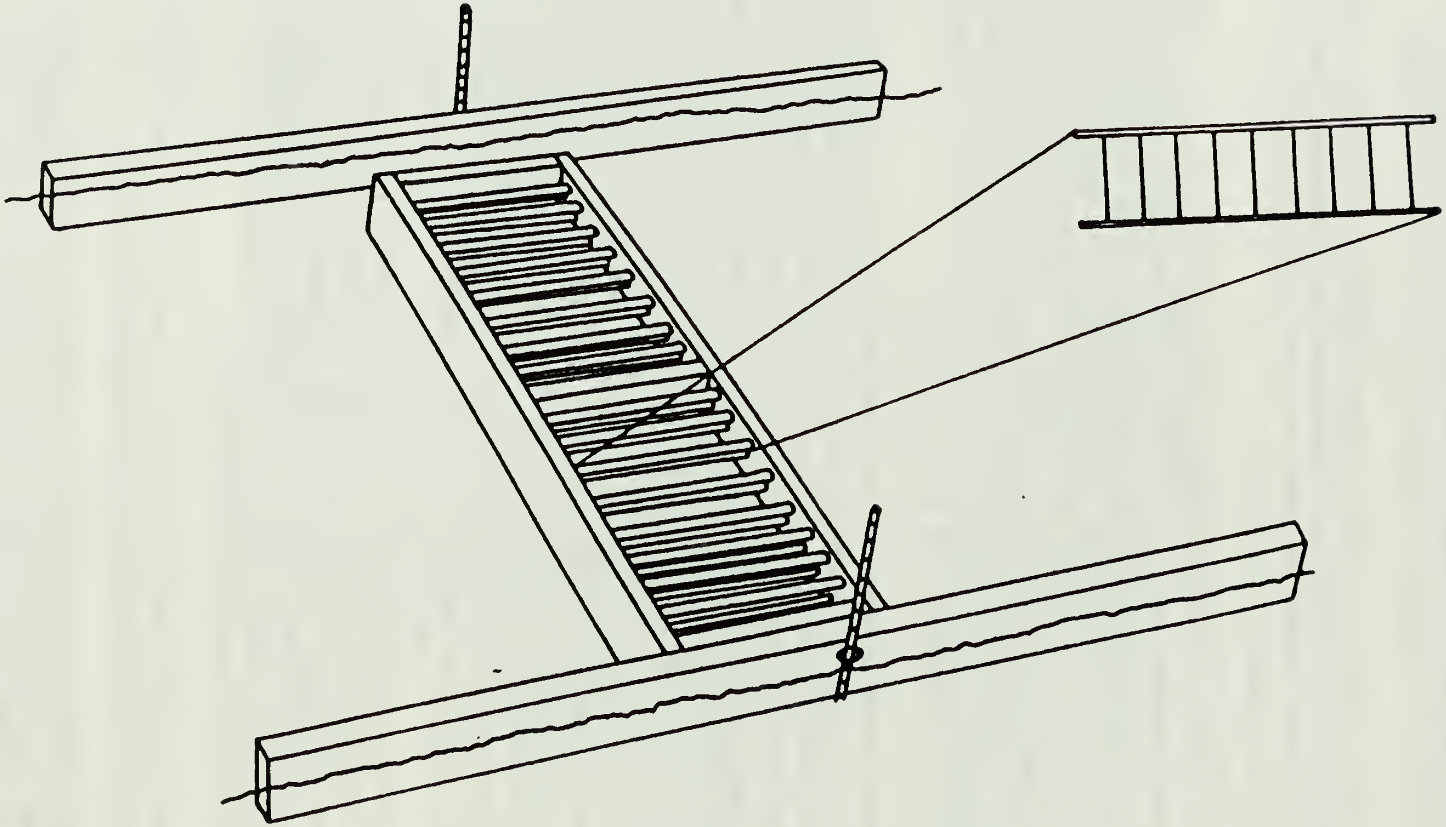


Figure 5. Periphytometer design: floating redwood frame holding racks of glass slides with enlarged view of a rack of 8 microscope slides.

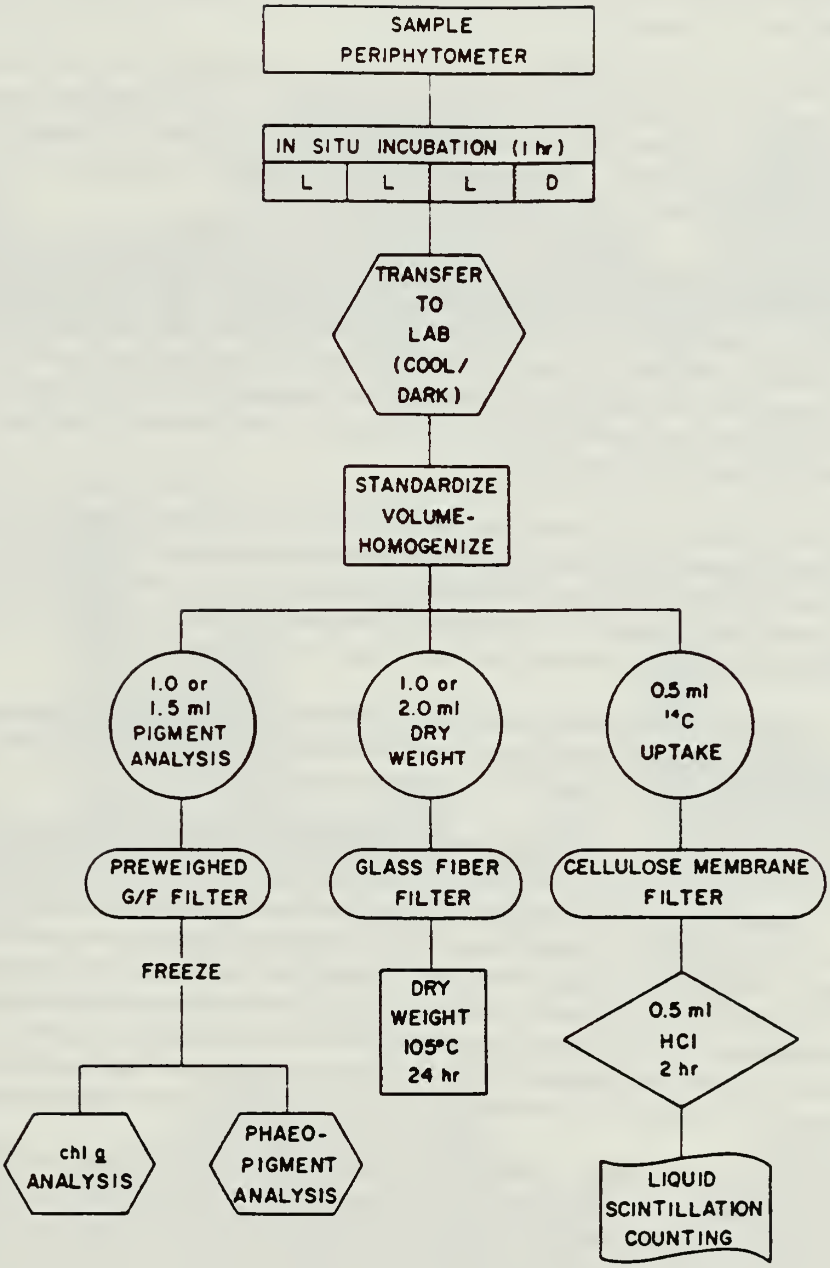


Figure 6. Flowchart of periphyton primary production and biomass determination.

amount of total carbon fixed during the period of incubation was made according to a method modified from Saunders et al. (1962). The primary production is reported as µg carbon fixed during the incubation (one hour) per square centimeter of the glass slide artificial substrate (µg cm^{-2} hr^{-1}).

Either 1.0 or 1.5 milliliters of the homogenate (depending on the homogenate density) was utilized for the determination of chlorophyll *a* and phaeopigment concentration. The homogenate was filtered on a 25 mm Whatman GF/C filter (0.45 micron pore size) under subdued light conditions. Filters were washed, frozen, and stored in the dark until extraction, which occurred within seven days of filtration.

Pigments were extracted by grinding for one minute in 8 ml of a 90 percent acetone solution. The extract was then filtered through a GF/C filter (0.45 microns) to remove filter material and brought up to 10 ml with 90 percent acetone. Chlorophyll *a* concentration was determined by a Hewlett Packard 8450A UV/VIS spectrophotometer (1 cm or 10 cm path length) using the SCOR/UNESCO equations (Strickland and Parsons, 1972). Chlorophyll *a* data are reported as µg chlorophyll *a* per square centimeter of the glass slide artificial substrate per week of growth (µg cm^{-2} wk^{-1}).

Dry weight determinations were completed by filtering either 1.0 ml or 2.0 ml of homogenate (depending on the homogenate density) onto a preweighed Whatman glass fiber filter (0.45 micron pore size), drying for a minimum of 24 hours at 105°C, and weighing on a Mettler H30 micro-balance. Dry weight data are reported as µg per square centimeter of the glass slide artificial substrate per week of growth (µg cm^{-2} wk^{-1}).

In addition to these periphyton biomass and primary production determinations, the community composition was also determined for periphyton colonizing the glass slides during the six to seven week period (Rice, unpubl. data).

HYDROLOGICAL BACKGROUND

Rainfall in the Everglades is highly seasonal. Approximately 80 percent of the mean annual rainfall occurs in southern Florida during the six-month period extending from May to October. Historically, water levels were largely a function of local rainfall and natural runoff from the northern Everglades. However, with the building of water management impoundments, water conditions in the Shark River Slough became a function of the precipitation and the release of stored surface water and flood water discharges routed through the four S-12 control structures located along the northern park boundary.

During this study, precipitation and surface water deliveries varied from the period of record mean (Fig. 7). Rainfall in the area of the study site from April 1983 to September 1984 was 86 percent of the period of record (1949-1983) mean, while surface water discharge into Shark River Slough through the four S-12 structures was 120 percent of the 1964-1984 mean. Monthly rainfall during the first six months of the study (April-September 1983) approximated the period of record mean while surface water deliveries were slightly below the mean. From October 1983 to April 1984, rainfall decreased and remained at typical dry season amounts, while surface water deliveries were consistently higher than the period of record mean. Consequently, stage at the study site did not begin to recede until January 1984 (Fig. 8). The seasonal stage recession continued until May 1984 when the lowest water depth (0.28 m) during the study was recorded. An intense rainfall event in late May 1984 ended the drydown. Although rainfall from June to September 1984 was below the mean, surface water deliveries were consistently above the mean so that wet conditions persisted at the study site.

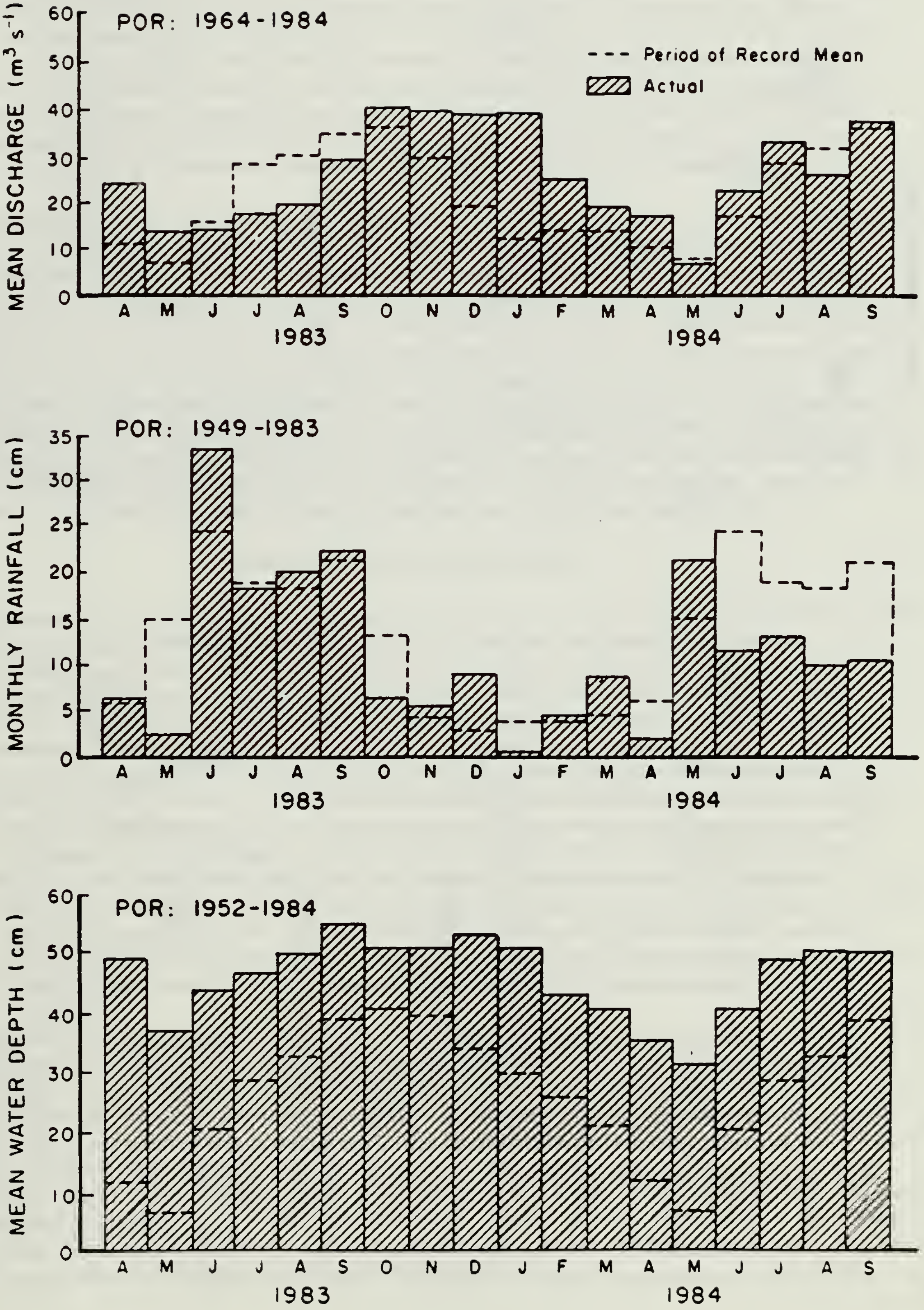
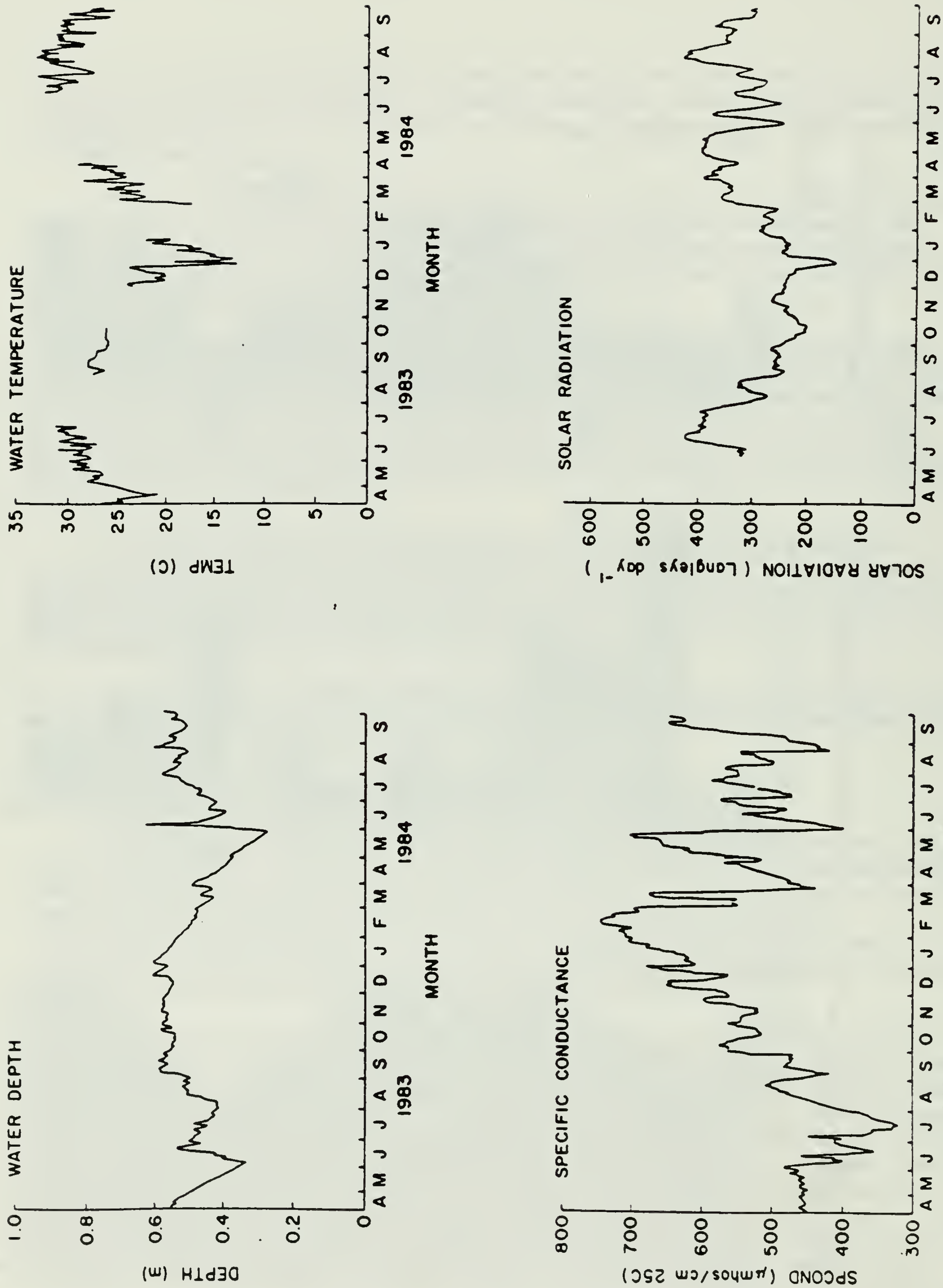


Figure 7. Mean surface water discharge from the S-12 structures, monthly rainfall into the Shark River Slough, and mean water depth at Station P-33 (April 1983 - September 1984).


WATER DEPTH
DEPTH (m)
1.0
0.8
0.6
0.4
0.2
0
A M J J A S O N D J F M A M J J A S
1983
1984
MONTH
WATER TEMPERATURE
TEMP (C)
35
30
25
20
15
10
5
0
A M J J A S O N D J F M A M J J A S
1983
1984
MONTH
SPECIFIC CONDUCTANCE
SPCOND (μmhos/cm 25C)
800
700
600
500
400
300
A M J J A S O N D J F M A M J J A S
1983
1984
MONTH
SOLAR RADIATION
SOLAR RADIATION (Langleys day⁻¹)
600
500
400
300
200
100
0
A M J J A S O N D J F M A M J J A S
1983
1984
MONTH

Water depth at the study site ranged from 0.28 m to 0.63 m. Overall, water levels in the Slough were above normal for the duration of the study. Water depth data from Shark Slough hydrological station P-33 (Fig. 7), located about 5 km east of the study site (Fig. 2), indicates that from water years 1975 to 1984, water year 1983 was the wettest and water year 1984 was the second wettest. While the higher water levels may have dampened water temperature fluctuations and affected specific conductance, the overall effect was probably minimal and would have affected the experimental channels and controls equally. Further, higher water depths would dilute the dosed nutrients and dampen the biological response observed, compared to the response expected under more normal water conditions.

Seasonal patterns in daily water temperature, specific conductance, and solar radiation are presented in Figure 8. Water temperature peaked both years between 32°C and 34°C during the summer (June-August). The lowest water temperatures (13°C) occurred during December 1983. Solar radiation reached maximum intensity from April to August and its lowest level from October to January. Specific conductance within the Shark River Slough has been shown to respond to rainfall, evaporation, and the delivery of more highly ionized canal waters from further north in the south Florida water management system (Flora and Rosendahl, 1982b). Seasonal specific conductance patterns at the study site are similar to those reported by Flora and Rosendahl (1981). Specific conductance is lowest during periods of heavy rainfall (July 1983 and May 1984) and highest during periods of seasonal drydown (April-May 1984) and high surface water delivery (October 1983-January 1984). Specific conductance during the study ranged from 310 μmhos cm^{-1} to 740 μmhos cm^{-1}.

EXPERIMENT 1 RESULTS

The purpose of experiment 1 was to assess the impact of short-term increased dissolved orthophosphate (PO_4-P) and dissolved nitrate (NO_3-N) loading on Shark Slough water chemistry, periphyton productivity, and periphyton and macrophyte community structure. To accomplish this, experimental channel B (Fig. 3) was dosed continuously with a dissolved orthophosphate + dissolved nitrate solution from April 1983 to September 1984. During this time, the concentration of dissolved nitrate was increased an average of 84.5 μg L^{-1} (as N) over background levels, or approximately eight times the concentration found in the untreated channel (mean = 11.2 μg L^{-1} as N). The total resulting dissolved nitrate concentration (mean = 95.7 μg L^{-1}) is approximately 14 percent of the maximum dissolved nitrate concentration (700 μg L^{-1} as N) allowed by the 1984 Memorandum of Agreement (MOA, 1984) (Rosendahl and Rose, 1979) which establishes standards for the quality of water delivered to Everglades National Park. Six-week mean dissolved nitrate additions to the experimental channel B varied from 35 to 140 μg L^{-1} (as N) (Fig. 9) due to fluctuations in nutrient volume dosed, seasonal variations in rainfall and water delivery to Shark River Slough, and changes in periphyton and macrophyte community structure which affected discharge within experimental channel B.

Dissolved orthophosphate concentrations were increased an average of 28.5 μg L^{-1} (as P) in experimental channel B representing almost five times the concentration of dissolved orthophosphate (mean = 5.8 μg L^{-1} as P) found in the controls. The resulting dissolved orthophosphate concentration (mean = 34.3 μg L^{-1} as P) is slightly higher than the 20 μg L^{-1} (as P) maximum standard for water delivered to the park under the Memorandum of Agreement, but much less than the average dissolved orthophosphate concentration typically found in canals which drain the Everglades Agricultural Area (Lutz, 1977; Dickson et al., 1978; CH_2M HILL, 1978; Mattraw et al., 1987; Scheidt et al., 1988). During experiment 1, dissolved orthophosphate additions to experimental channel B ranged from 12 to 47 μg L^{-1} (as P) (Fig. 9). Again, the concentration varied as a function of discharge through experimental channel B.

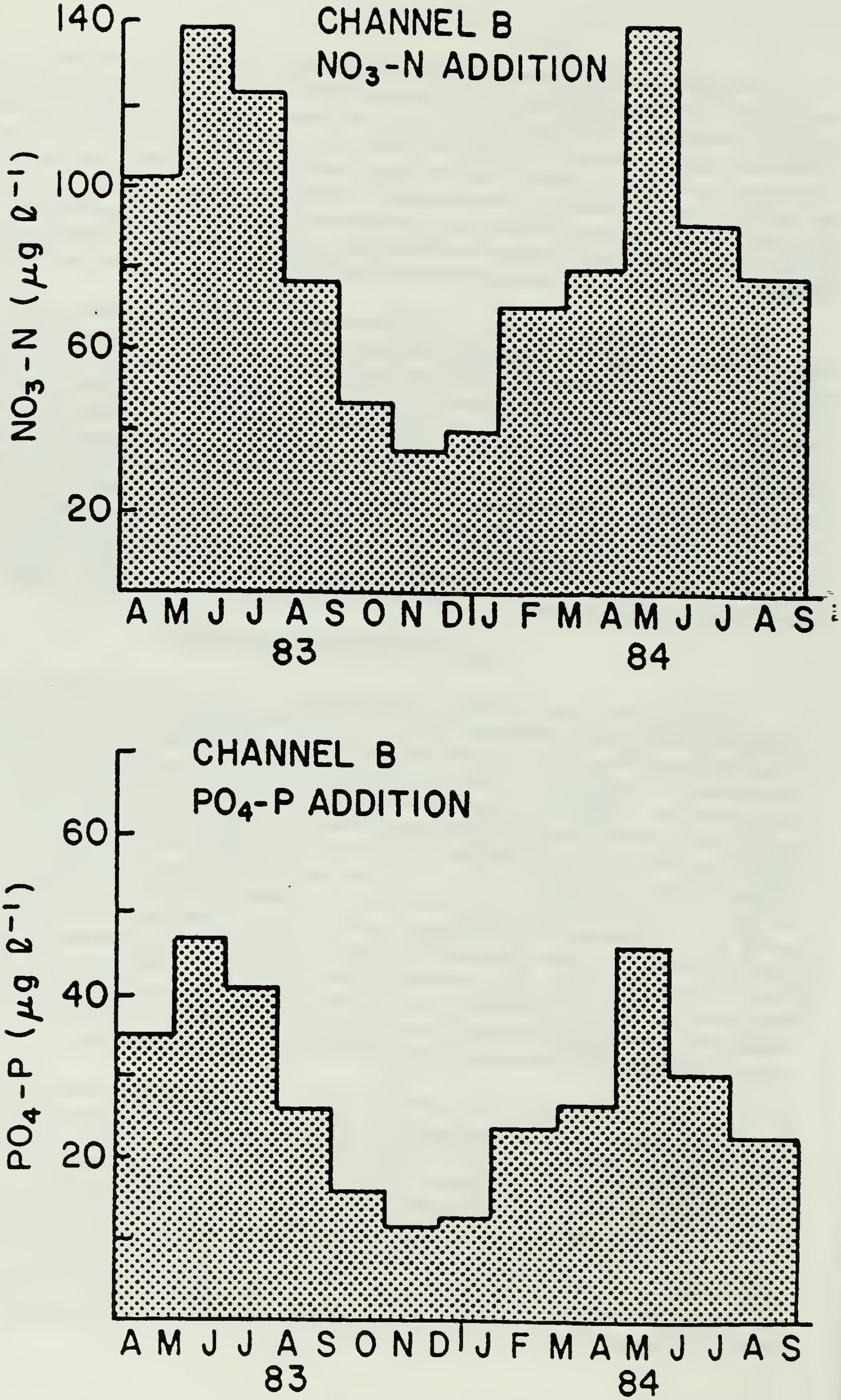


Figure 9. Six week mean dissolved nitrate and dissolved orthophosphate addition to experimental channel B.

Qualitatively, the responses of the periphyton and macrophyte assemblages to enhanced dissolved nitrate and dissolved orthophosphate loading were both rapid and dramatic. Within six weeks of nutrient dosing, the native floating, calcareous periphyton mat dissipated. The disappearance of the algal mat occurred only within experimental channel B. Channels A and C and the control sites which received no nutrient additions during this time were not affected. The disappearance of the algal mat brought about several physical changes in experimental channel B. Discharge through the channel increased relative to untreated channels A and C (Fig. 10, Fig. 20). After dissipation of the algal mat, light transmission increased throughout the water column, as indicated by radiometer measurements. Gradually, the macrophyte community assemblage in experimental channel B also changed. These changes in the macrophyte community are documented in a companion report (Walker et al., in prep.). A second report is planned to document the periphyton community structure for the duration of the study.

Water Chemistry

Figures 11 and 12 present the average dissolved orthophosphate and dissolved nitrate concentrations occurring at sampling sites within experimental channel B for each six to eight week period preceding periphyton sampling. Dissolved orthophosphate and dissolved nitrate concentrations varied as a function of discharge and channel nutrient uptake capacity. Mean concentrations during experiment 1 at all sites in experimental channel B and the control are presented for dissolved orthophosphate, total phosphorus, dissolved ammonia-nitrogen, dissolved nitrate, dissolved organic nitrogen, and total nitrogen in Figures 13 and 14. Analysis of variance results indicate that significant ($P < 0.001$) differences were found between concentrations in experimental channel B and the control sites for dissolved nitrate, dissolved orthophosphate, and total phosphorus (Table 4). No significant ($P > 0.05$) differences were found between channels for dissolved ammonia-nitrogen, dissolved organic nitrogen, or total nitrogen.

The nutrient uptake capacity of the experimental channel was assessed by measuring nutrient concentrations at 10 m, 20 m, 35 m, 65 m, and 95 m downstream from the point of nutrient addition. For a complete listing of the data obtained see Flora et al. (1986). Analysis of variance (Table 4) indicated a significant difference of dissolved nitrate ($P < 0.01$) and dissolved orthophosphate ($P < 0.001$) concentrations between the sites within experimental channel B. No significant difference ($P > 0.05$) was found between sites within channel B for dissolved ammonia-nitrogen, dissolved organic nitrogen, total nitrogen, or total phosphorus or for any water quality parameter between the two control sites.

Figures 15 and 16 show the change of dissolved orthophosphate concentration and dissolved nitrate concentration with distance in experimental channel B. Dissolved orthophosphate was reduced from a mean concentration of 25.3 $\mu g\ L^{-1}$ (as P) at 10 m to a mean concentration of 10.1 $\mu g\ L^{-1}$ (as P) at 95 m (control = 5.8 $\mu g\ L^{-1}$ (as P)). Similarly, dissolved nitrate decreased from a mean concentration of 62 $\mu g\ L^{-1}$ (as N) at 10 m to a mean concentration of 29 $\mu g\ L^{-1}$ (as N) at 95 m (control = 11.2 $\mu g\ L^{-1}$). While these data indicate a very rapid uptake of both dissolved orthophosphate and dissolved nitrate in the experimental channel, it must be remembered that this was a limited duration (18-month) experiment. It is probable that the ability of the marsh system to assimilate nutrients changes with time, loading rate, and season. In addition, little is known of the conditions in which the marsh system may release stored nutrients.

Periphyton Biomass and Primary Production

In order to assess the impacts of the dissolved nitrate and dissolved orthophosphate loading upon the periphyton community, periphyton biomass, primary production, and

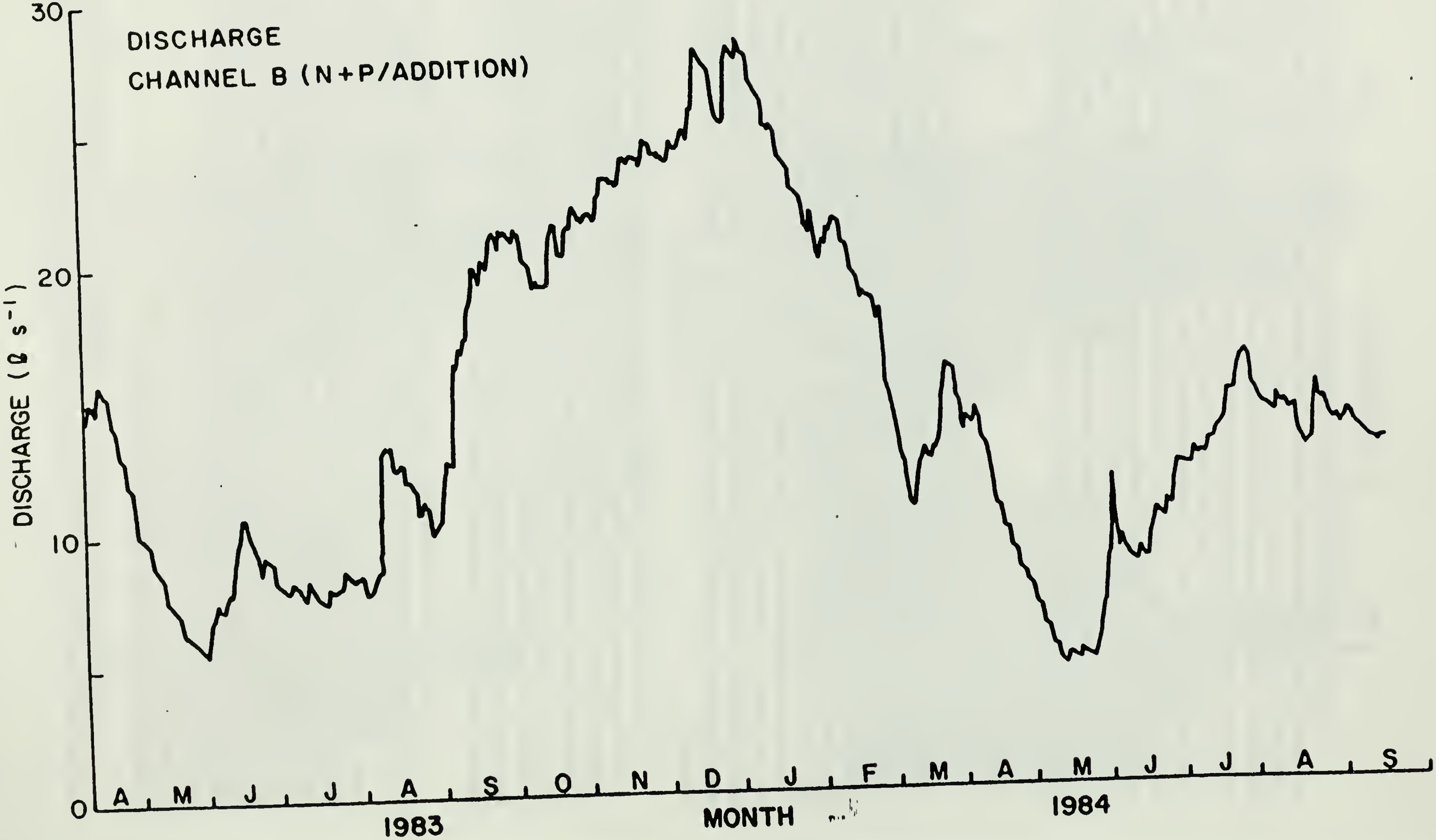


Figure 10. Discharge in experimental channel B.

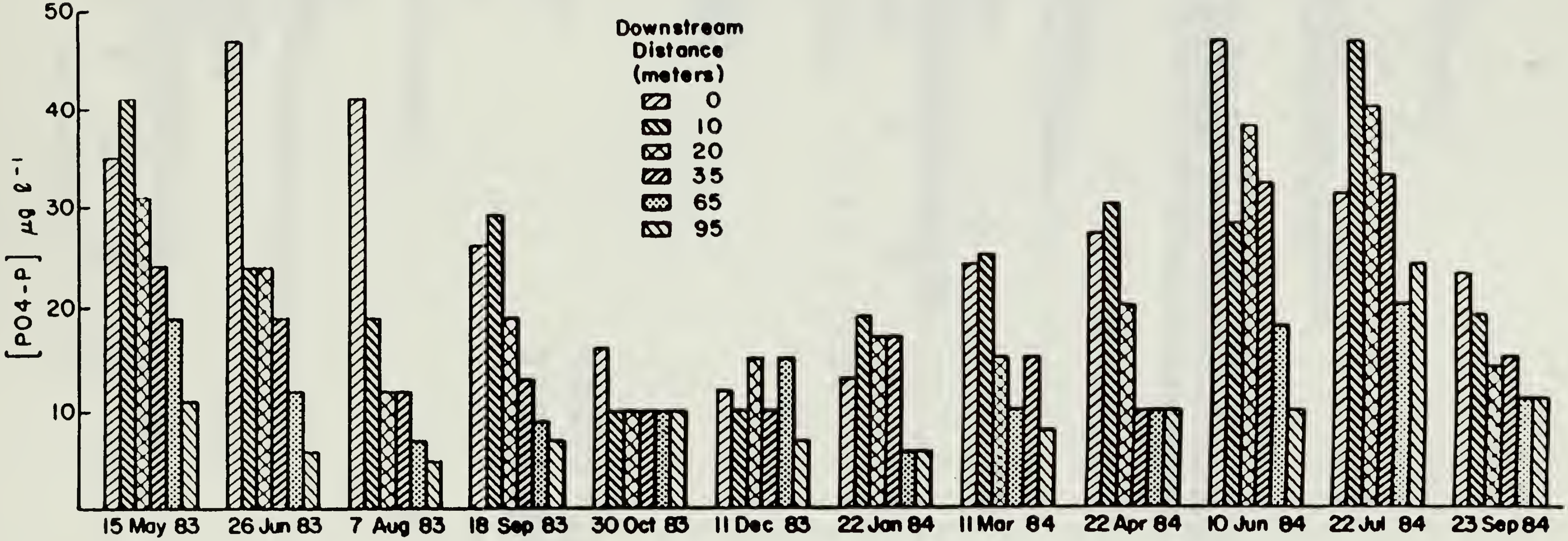


Figure 11. Six week mean dissolved orthophosphate concentration (all sites) in experimental channel B.

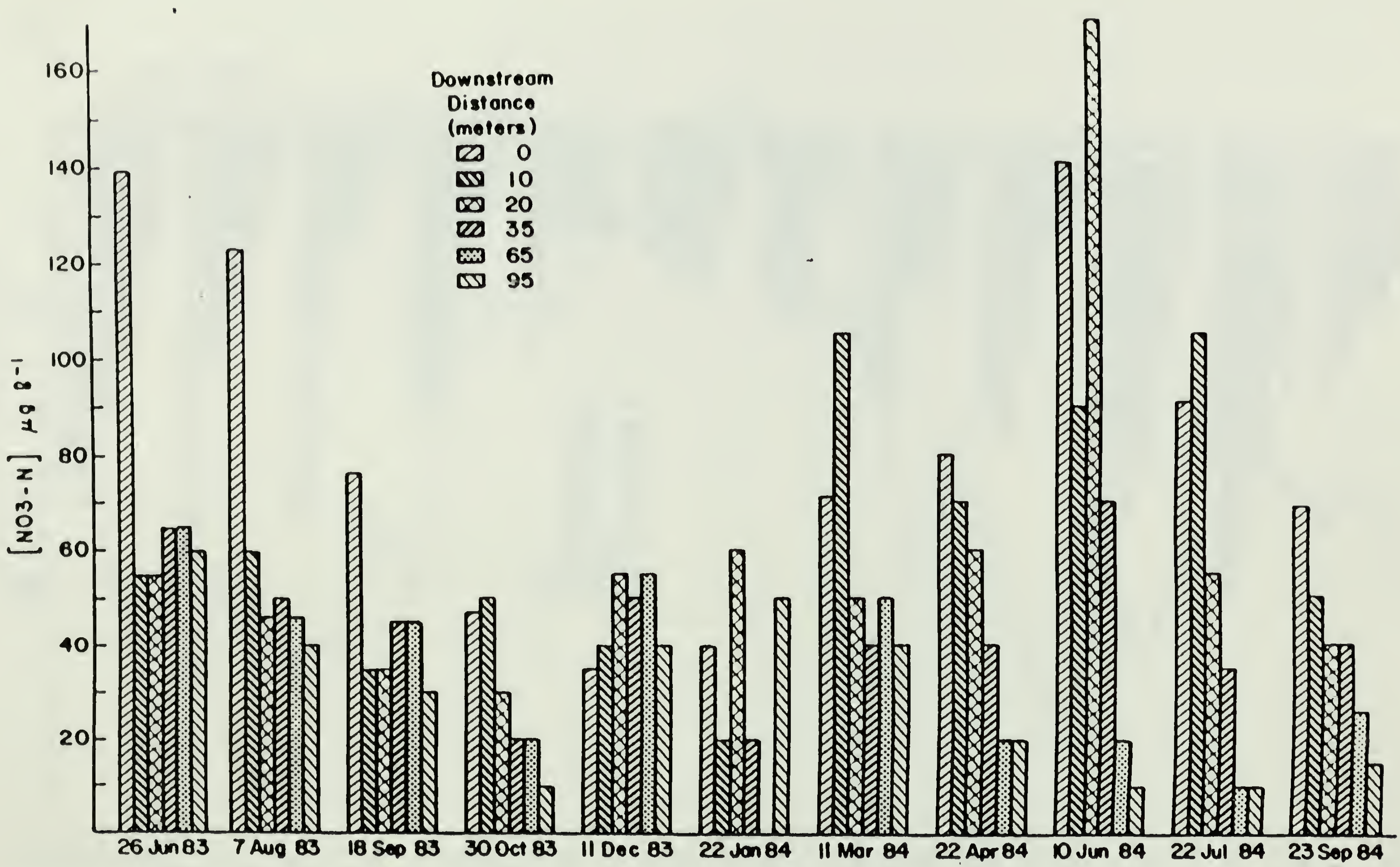


Figure 12. Six week mean dissolved nitrate concentration (all sites) in experimental channel B.

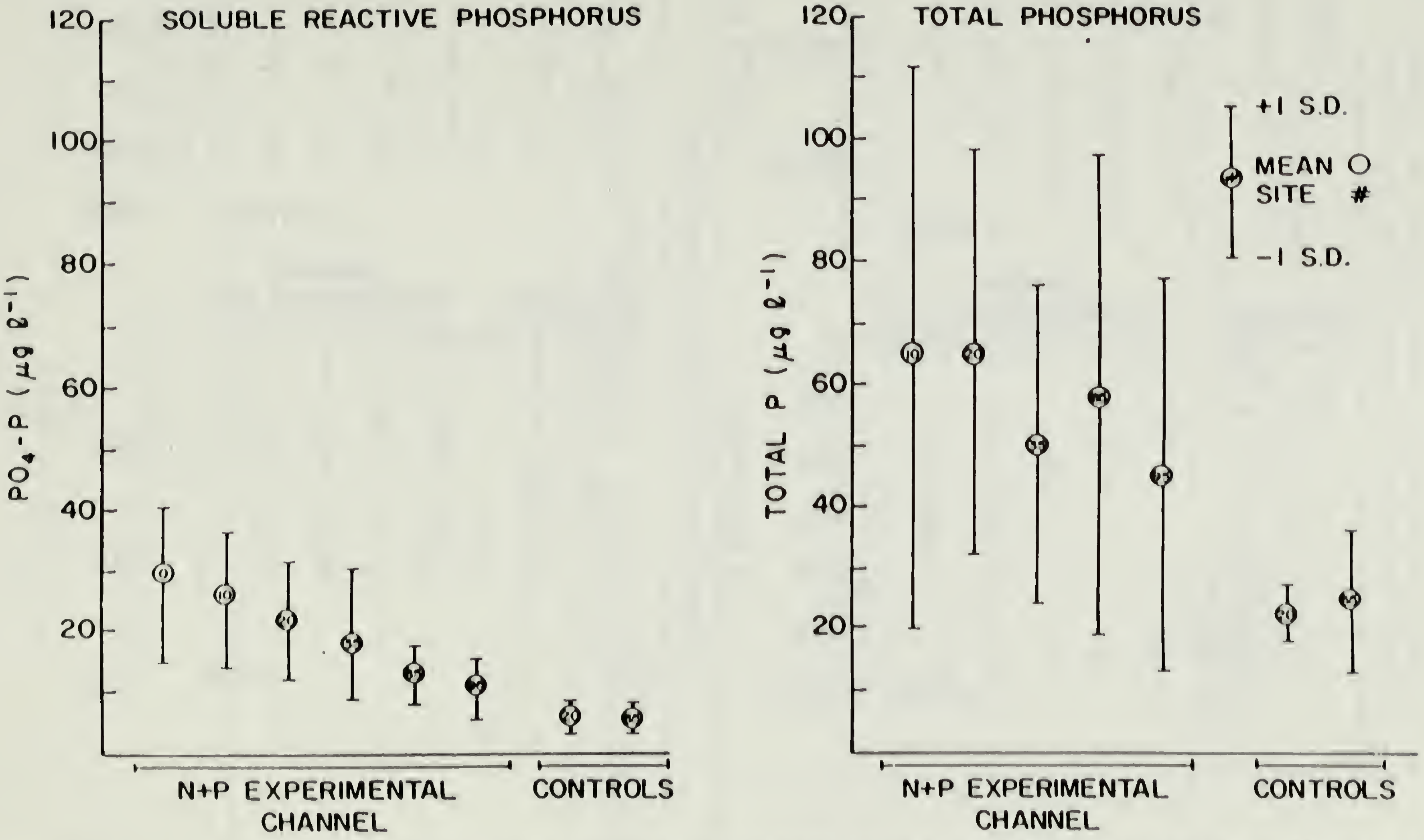
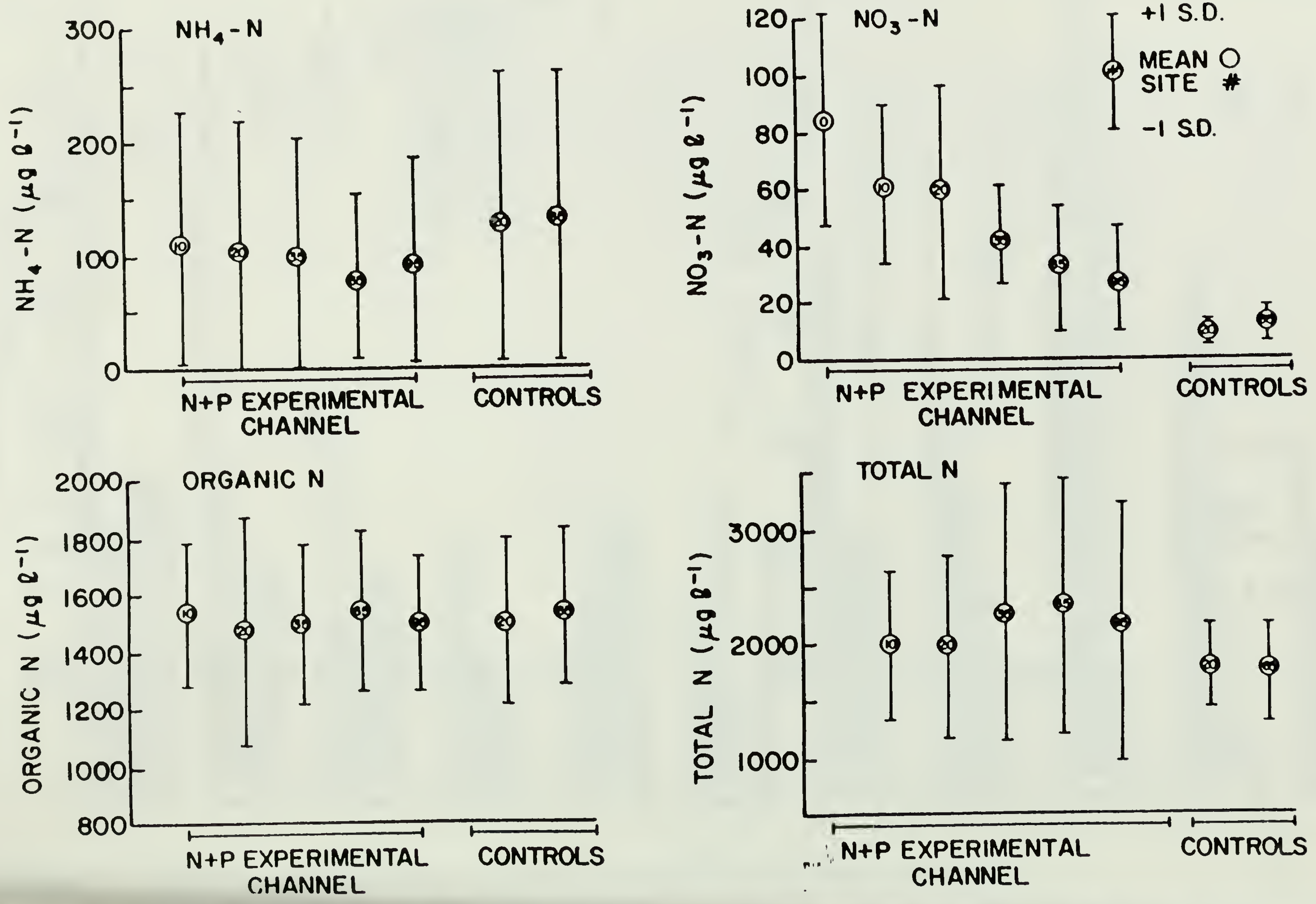


Figure 13. Mean concentration (by site) within experimental channel B and controls for dissolved orthophosphate (n=27) and total phosphorus (n=13) (May 1983 - September 1984).



Mean concentration [illegible] and controls for ammonia, nitrate, organic nitrogen,

Table 4. Results of between-channel (experimental channel B vs. control) and within-channel (among sites) analysis of variance (ANOVA) for experiment 1 water quality parameters.

BETWEEN-CHANNEL (B VS. CONTROL) ANOVA RESULTS

Parameter	Channel B vs. Control Channel	
	Main Effect (F)	Significance (F)
NO_3-N	13.459	***
PO_4-P	18.282	***
NH4-N	0.431	NS
ORG-N	0.138	NS
TN	0.887	NS
TP	8.589	***

WITHIN-CHANNEL (AMONG SITES) ANOVA RESULTS

Parameter	Channel B		Control	
	Ratio (F)	Significance (F)	Ratio (F)	Significance (F)
NO_3-N	5.042	**	0.360	NS
PO_4-P	8.412	***	0.057	NS
NH4	0.065	NS	0.000	NS
ORG-N	0.139	NS	0.155	NS
TN	0.244	NS	0.125	NS
TP	0.992	NS	0.008	NS

**Sig at 0.01 level
***Sig at 0.001 level
NS not sig (P > 0.05)

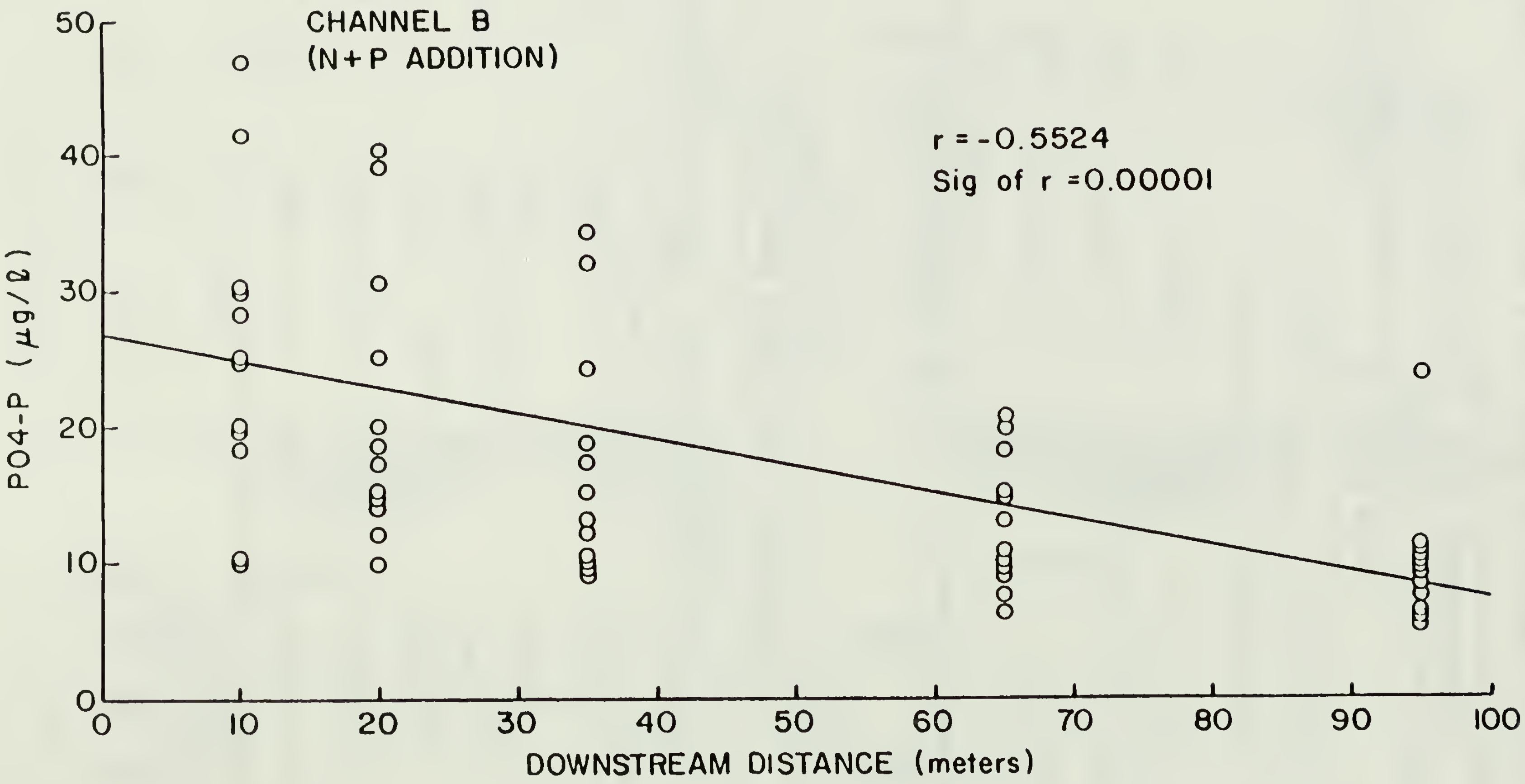


Figure 15. Change in dissolved orthophosphate concentration with distance in experimental channel B (April 1983 - September 1984).

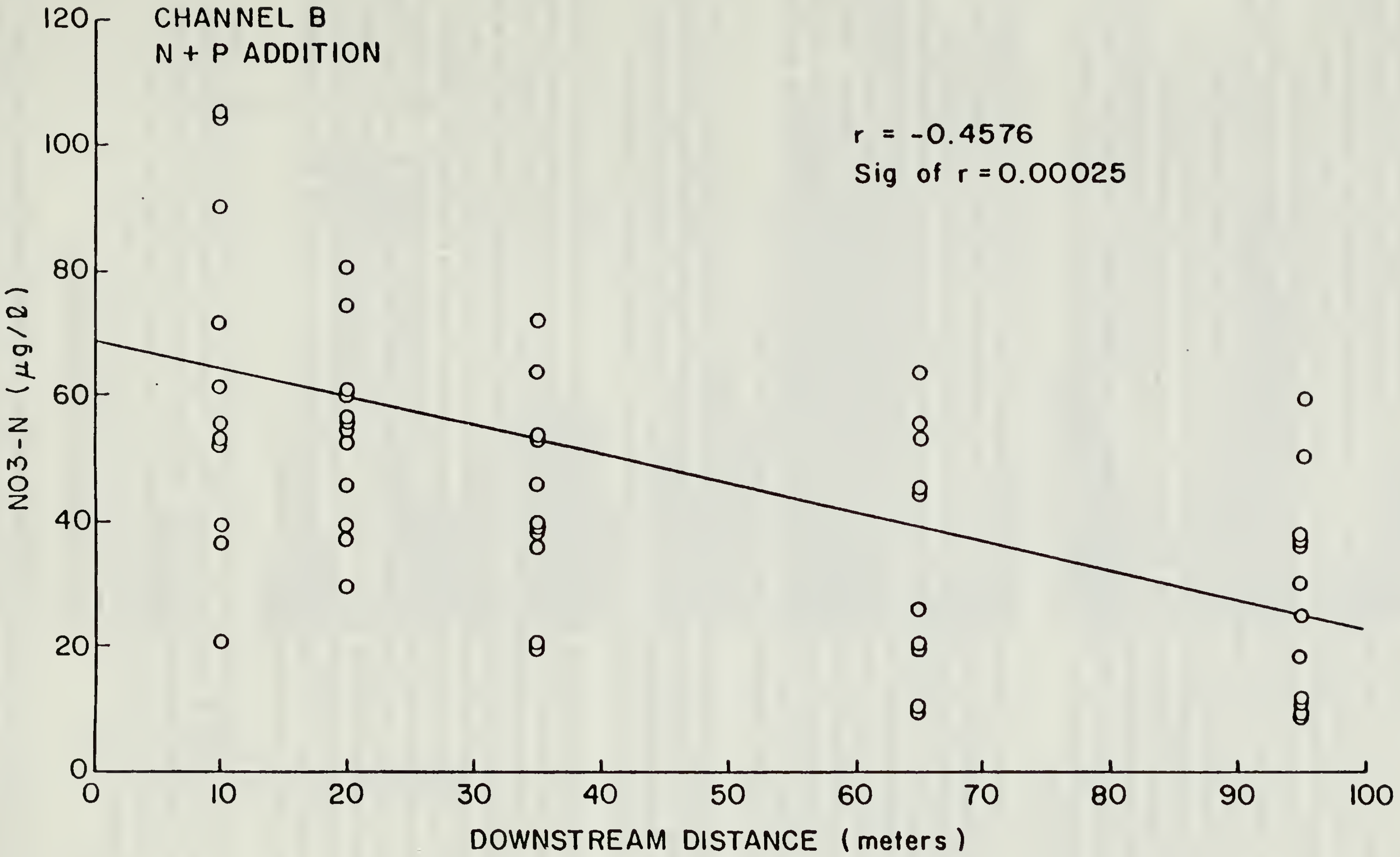


Figure 16. Change in dissolved nitrate concentration with distance in experimental channel B (April 1983 - September 1984).

community structure data were collected every six to seven weeks at the control sites and at five locations (10 m, 20 m, 35 m, 65 m, and 95 m) downstream of the point of nutrient input. Figures 17 and 18 present biomass data (i.e., a measure of the amount of algae present) from periphytometers suspended at the control sites and in experimental channel B. These data indicate that increased dissolved nitrate and dissolved orthophosphate loading had a significant impact on periphyton biomass in experimental channel B when compared to the control sites (Table 5). The mean chlorophyll *a* concentration in experimental channel B (55 µg cm^{-2} wk^{-1}) was more than 15 times greater ($P < 0.001$) than the mean chlorophyll *a* concentration determined from periphytometers at the control sites (3.5 µg cm^{-2} wk^{-1}). Similarly, biomass as determined by dry weight from algae grown on glass slides in experimental channel B (mean = 0.13 µg cm^{-2} wk^{-1}) was an average 13 times greater than the dry weight biomass from periphytometers at the control sites (mean = 0.01 µg cm^{-2} wk^{-1}). These biomass differences are also reflected in changes in periphyton community structure (unpublished data).

No significant difference ($P > 0.05$) was found for either chlorophyll *a* concentration or dry weight determinations among the sites within experimental channel B (Table 5). This is interesting in view of the fact that significant differences were noted for both dissolved orthophosphate ($P < 0.001$) and dissolved nitrate ($P < 0.01$) concentrations at sites downstream from the nutrient input in this channel. This indicates that the factors determining periphyton response to increased nutrient loading are complex and cannot accurately be described by a simple linear relationship between nutrient concentration and periphyton biomass. This can be seen to some extent in the data presented in Figures 17 and 18. An algal bloom occurred at 65 m and 95 m in July and September 1984, even though nutrient concentrations were lower than at sites further upstream in the experimental channel.

While biomass measurements such as chlorophyll *a* and dry weight are important in determining the response of periphyton standing crop to environmental changes, it is also important to measure changes in the rate of primary production. This was accomplished using ^{14}carbon uptake methodology to determine the rate of carbon fixation by periphyton.

The results of primary production determinations in experimental channel B and at the control sites are presented in Figure 19. On a per unit area basis, the overall mean primary production at sites located in experimental channel B (mean = 0.279 µg carbon fixed cm^{-2} hr^{-1}), is approximately nine times greater than the overall mean primary production (on a per unit area basis) measured at the control sites (mean = 0.031 µg carbon fixed cm^{-2} hr^{-1}) (Fig. 20). This correlates with the increase in periphyton biomass found on the glass slide artificial substrates in experimental channel B when compared with the control sites. However, primary production (i.e., the rate of the primary production), when assessed on a per-unit-dry-weight basis (which compensates for the increased biomass) did not differ significantly ($P > 0.05$) either between the control sites (mean = 0.61 µg carbon fixed/µg dry weight per hour) and experimental channel B (mean = 0.60 µg carbon fixed/µg dry weight per hour) or among the downstream sites within experimental channel B (Table 5).

Figure 20 summarizes the results of the biomass and primary production rates in experimental channel B and at the control sites. These data show that a relatively minor increase in dissolved orthophosphate plus dissolved nitrate significantly increased overall primary production as measured by chlorophyll *a*, dry weight, and carbon fixation, while primary productivity on a per-unit-dry-weight basis remained unaltered.

EXPERIMENT 2 RESULTS

Less than six weeks after the commencement of dissolved orthophosphate plus dissolved nitrate dosing into experimental channel B, it became apparent that major qualitative

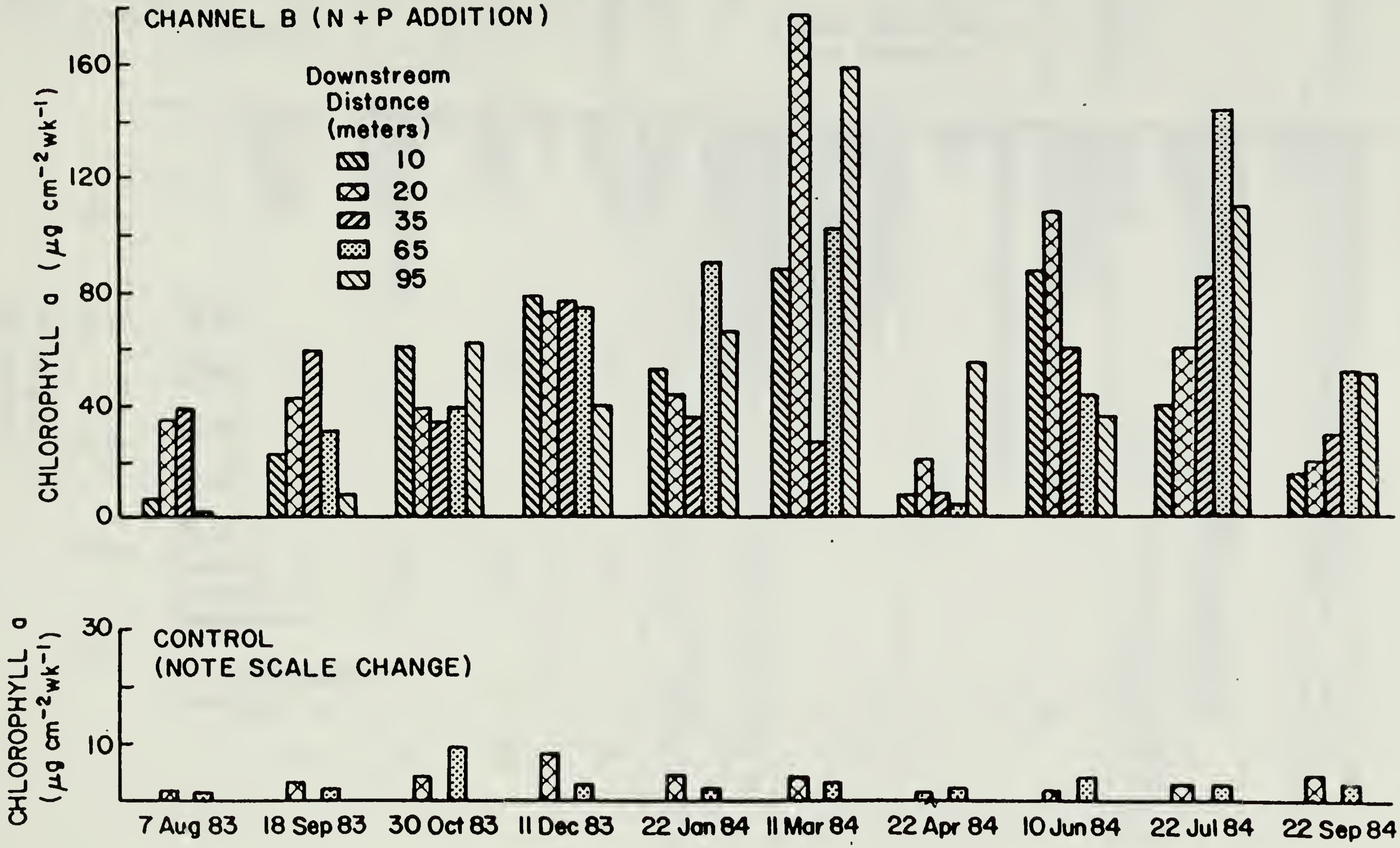


Figure 17. Chlorophyll a concentrations from periphytometers at control sites and five locations in experimental channel B.

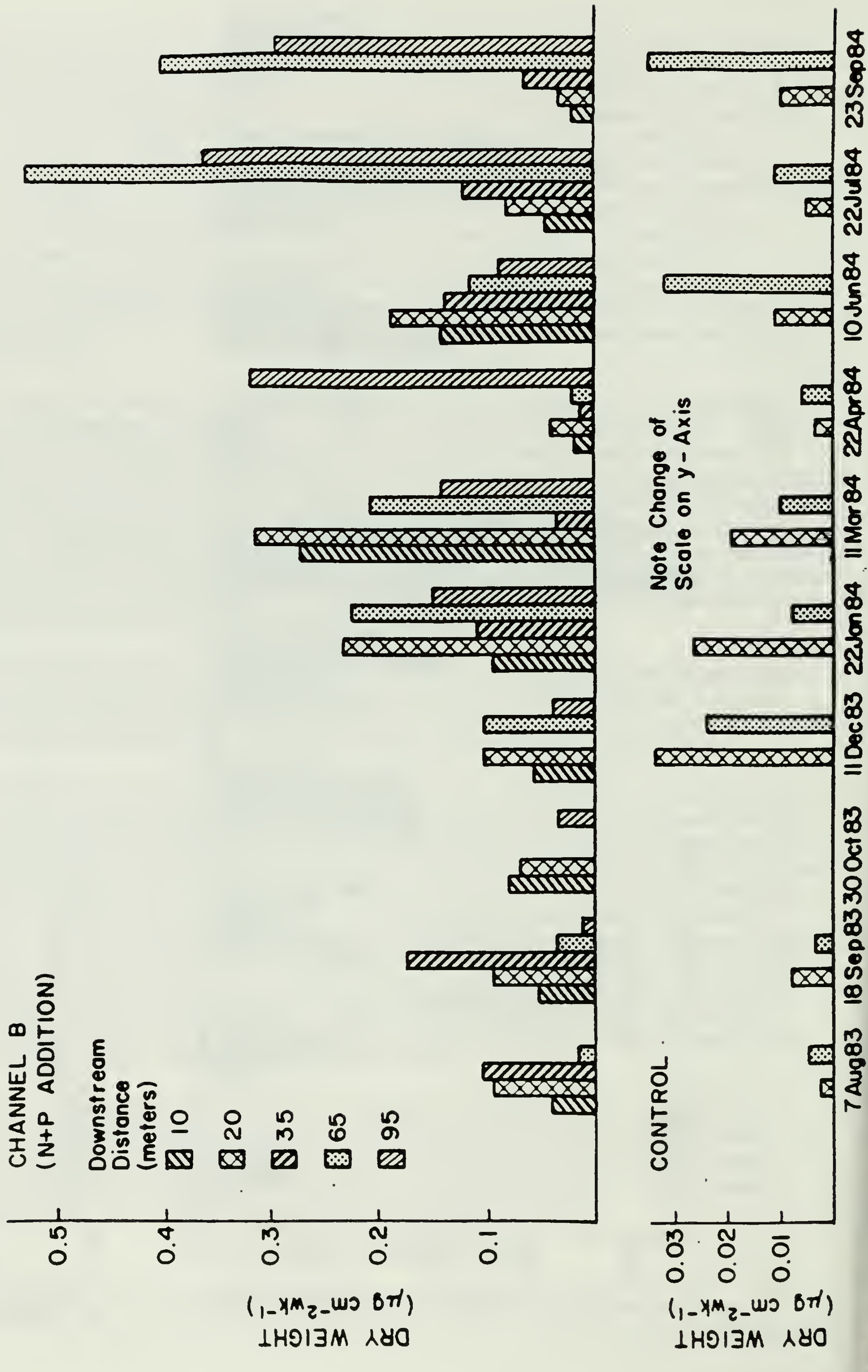

CHANNEL B
(N+P ADDITION)
Downstream Distance (meters)
10
20
35
65
95
DRY WEIGHT (µg cm⁻²wk⁻¹)
0.5
0.4
0.3
0.2
0.1
CONTROL
Note Change of Scale on y-Axis
DRY WEIGHT (µg cm⁻²wk⁻¹)
0.03
0.02
0.01
7Aug83
18Sep83
30Oct83
11Dec83
22Jan84
11Mar84
22Apr84
10Jun84
22Jul84
23Sep84

Table 5. Results of between-channel (experimental channel B vs. control) and within-channel (among sites) analysis of variance (ANOVA) for experiment 1 productivity and biomass parameters.

BETWEEN-CHANNEL (B VS. CONTROL) ANOVA RESULTS

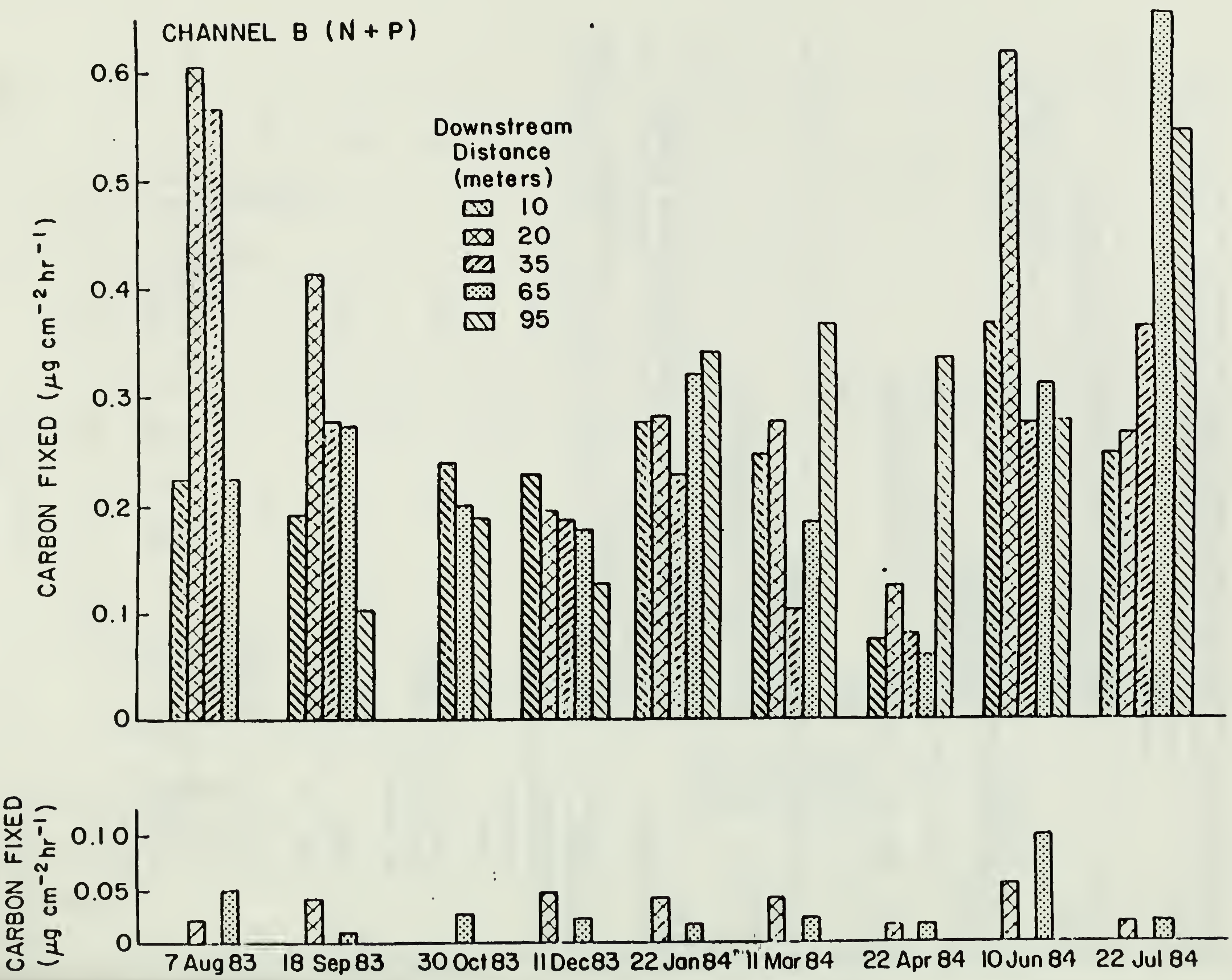
	Channel B vs. Control Channel	
Parameter	Ratio (F)	Significance (F)
Carbon Fixed (per unit area)	48.944	***
Carbon Fixed (per unit dry weight)	0.188	NS
CHLa (cm^{-2} wk^{-1})	12.337	***
Dry Wt (cm^{-2} wk^{-1})	7.968	**

*g carbon fixed/g dry weight

WITHIN-CHANNEL (AMONG SITES) ANOVA RESULTS

	Channel B		Control	
Parameter	Ratio (F)	Significance (F)	Ratio (F)	Significance (F)
Carbon Fixed (per unit (area)	0.78	NS	0.06	NS
Carbon Fixed (per unit day weight)	0.189	NS	0.227	NS
CHLa (cm^{-2} wk^{-1})	0.432	NS	0.046	NS
Dry Wt (cm^{-2} wk^{-1})	1.303	NS	0.154	NS

**Sig at 0.01 level
***Sig at 0.001 level
NS not sig (P > 0.05)


CHANNEL B (N + P)
Downstream
Distance
(meters)
10
20
35
65
95
CARBON FIXED (μg cm⁻² hr⁻¹)
0.6
0.5
0.4
0.3
0.2
0.1
0
CARBON FIXED
(μg cm⁻² hr⁻¹)
0.10
0.05
0
7 Aug 83
18 Sep 83
30 Oct 83
11 Dec 83
22 Jan 84
11 Mar 84
22 Apr 84
10 Jun 84
22 Jul 84

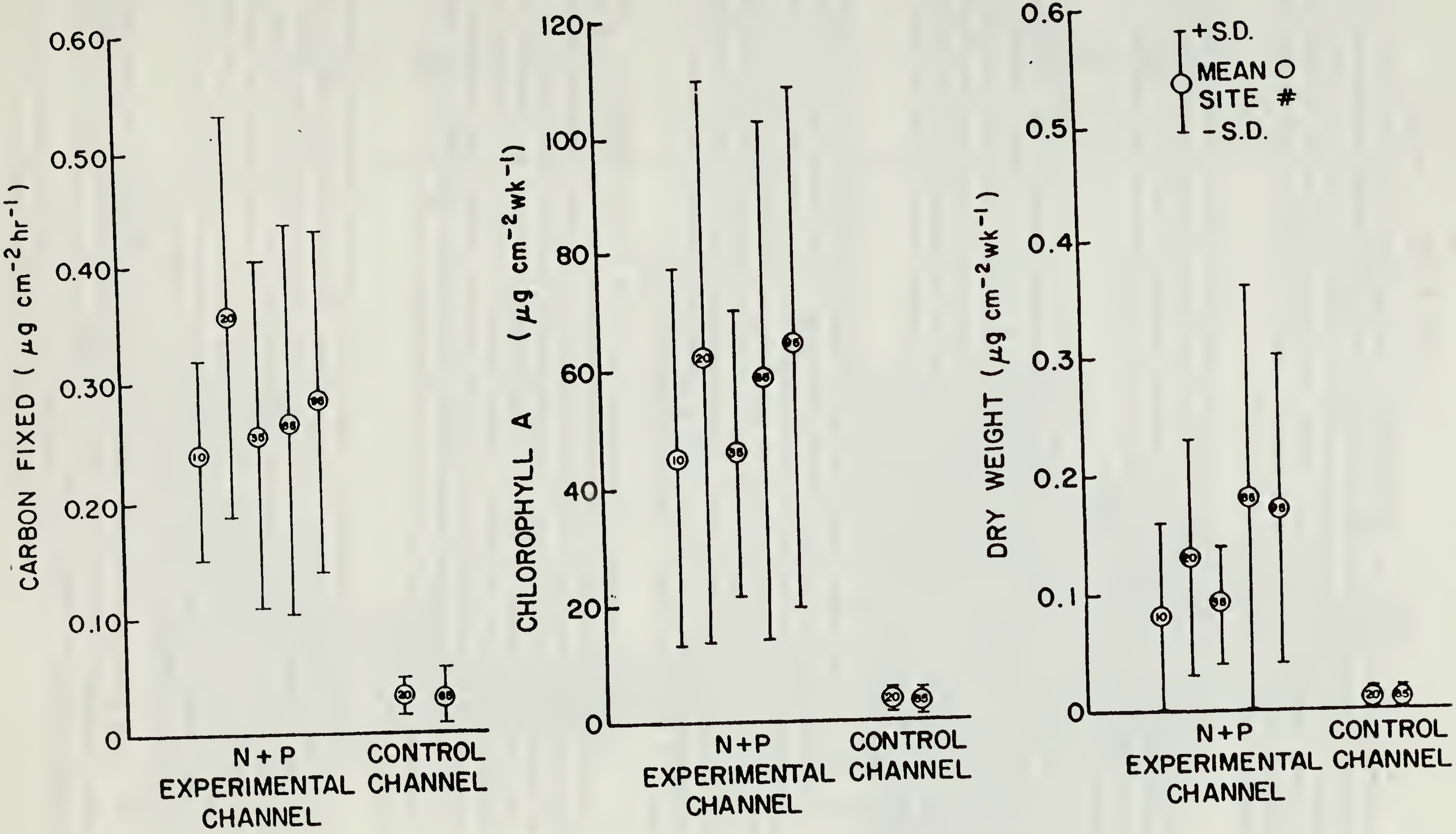


Figure 20. Summary of primary production and biomass data for experimental channel B (April 1983 - September 1984).

and quantitative changes were occurring in both the periphyton and macrophyte communities. Because of the importance of understanding the biological response to various water quality changes, a second set of experiments was begun in channels A and C in October 1983. The purpose of these experiments was to identify which nutrient(s) (dissolved orthophosphate, dissolved nitrate, or a combination of nutrients) were responsible for causing the dramatic biological response experienced in experiment 1.

To accomplish this, from October 1983 to September 1984 additions of dissolved orthophosphate only and dissolved nitrate only were made to channels A and C, respectively. As in experiment 1, nutrient uptake, periphyton community composition, biomass, primary production, and macrophyte community structure were examined to determine the system response to increased nutrient loading.

In experiment 2, the six-week mean dissolved orthophosphate concentration was increased an average of 27.5 $\mu g\ L^{-1}$ (as P) in experimental channel A, while the average concentration found at the untreated control sites during these 12 months was 5.8 $\mu g\ L^{-1}$ as P. The resulting dissolved orthophosphate concentration (addition plus background) in channel A (mean = 33.3 $\mu g\ L^{-1}$ as P) is slightly higher than the 20 $\mu g\ L^{-1}$ (as P) maximum standard for water delivered to Everglades National Park under the Memorandum of Agreement (MOA, 1984), and is comparable to the dissolved orthophosphate loading to channel B during experiment 1 (mean = 34.3 $\mu g\ L^{-1}$ as P).

The six-week mean dissolved nitrate concentration was increased an average of 85.2 $\mu g\ L^{-1}$ (as N) in experiment channel C during experiment 2. The average dissolved nitrate concentration found at the untreated control sites during this time was 11.2 $\mu g\ L^{-1}$ as N, resulting in total concentration (addition plus background) of dissolved nitrate in channel C of 96.4 $\mu g\ L^{-1}$ as N, 14 percent of the maximum allowable standard (700 $\mu g\ L^{-1}$ as N) for delivery to Everglades National Park under the Memorandum of Agreement. The concentration of dissolved nitrate found in channel C during experiment 2 is nearly identical to that found in channel B during experiment 1 (mean = 95.7 $\mu g\ L^{-1}$ as N).

The range of nutrient addition during experiment 2 varied considerably. This was due to the variation in discharge in the channels which responded to seasonal rainfall, surface water deliveries, changing macrophyte composition and biomass in channels, and the presence or absence of the periphyton mat. During experiment 2, six-week mean dissolved orthophosphate additions to channel A ranged from 9 to 75 $\mu g\ L^{-1}$ as P while six-week mean dissolved nitrate dosing to channel C ranged from 50 to 137 $\mu g\ L^{-1}$ as N (Fig. 21). As in experiment 1, the nutrient levels dosed and the resulting loading were comparable to, or less than levels found throughout canals draining the Everglades Agricultural Area, canals draining urban areas in South Florida, and structures discharging into the Water Conservation Areas (Scheidt et al., 1988).

Qualitative and quantitative changes in the experimental channels became apparent soon after the commencement of nutrient addition. In experimental channel A (dissolved orthophosphate only addition) the periphyton mat disappeared within eight weeks, while the mat remained in channel C (dissolved nitrate additional only) and the control sites. This caused discharge in channel A (Fig. 22) to increase to 21 percent greater than that in experimental channel C. Discharge in experimental channel A remained higher than discharge in experimental channel C until March 1984 when extensive algal blooms and increased growth of *Sagittaria* spp. began to impede channel A discharge.

The qualitative changes observed in experimental channel C were more subtle. The native periphyton mat disappeared after about eight months of dosing. Macrophyte community structure was also changed, as documented in a companion report (Walker et al., in prep.).

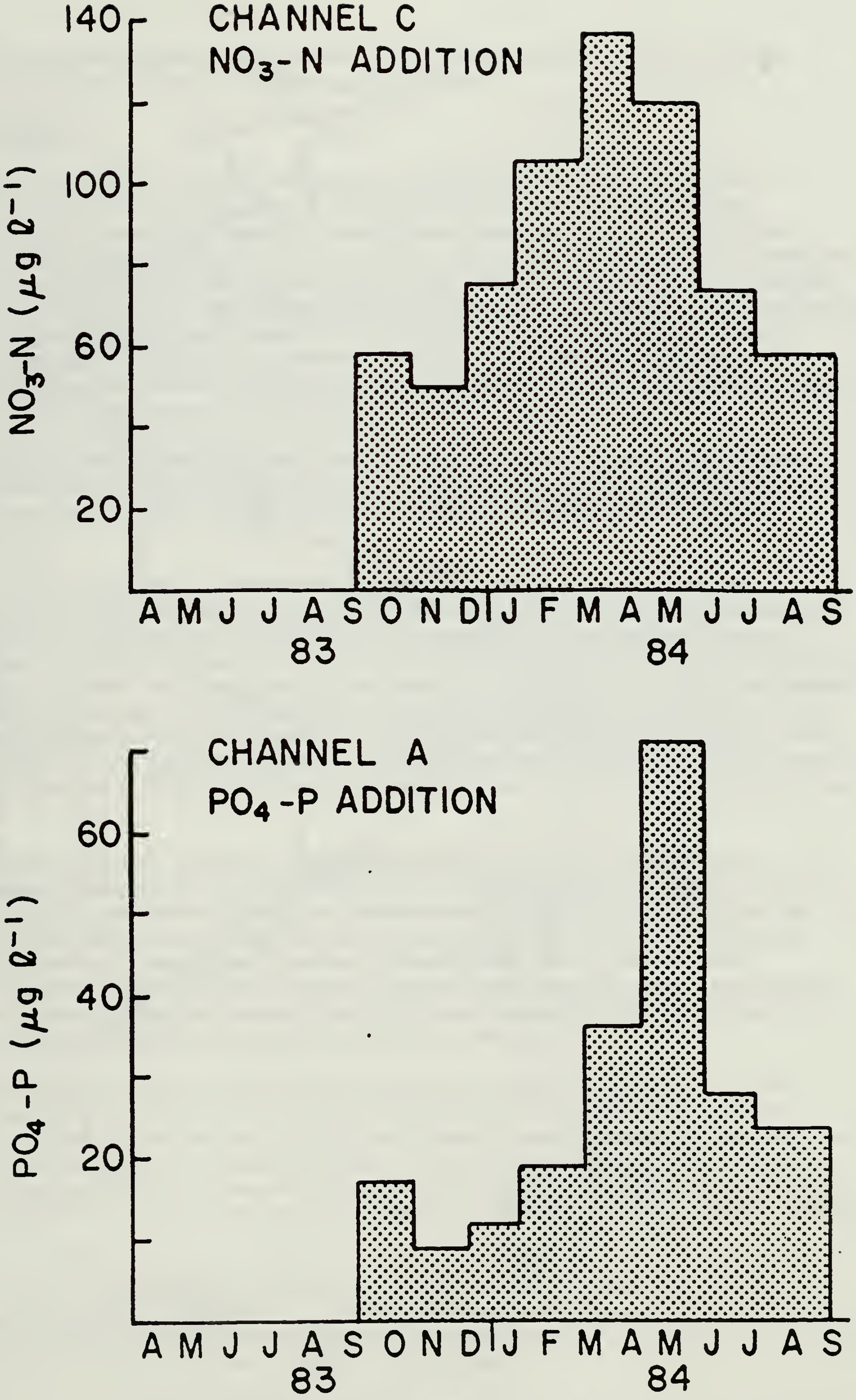
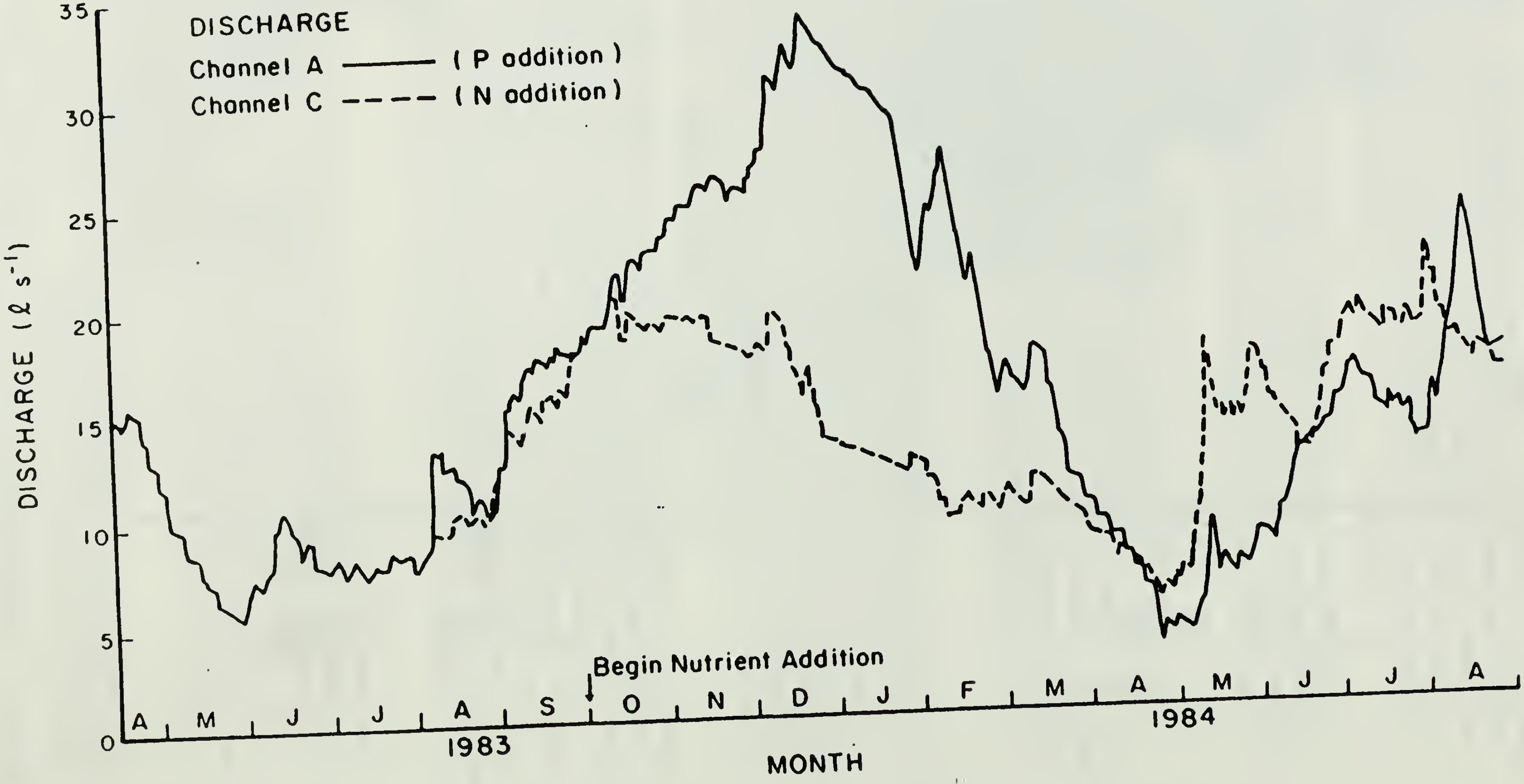


Figure 21. Six week mean dissolved orthophosphate addition to experimental channel A and dissolved nitrate addition to experimental channel C.



channel A and experimental channel C.

Blooms of non-attached algae, which occurred during low-flow periods in experimental channels A and B, did not occur in experimental channel C.

Water Chemistry

Figure 23 presents six-week mean dissolved orthophosphate concentrations in experimental channel A for the duration of experiment 2. Dissolved orthophosphate concentrations in experimental channel A generally were less than 20 $\mu g\ L^{-1}$ (as P) from October 1983 to April 1984, a period of unusually high discharge. Dissolved ortho-phosphate concentrations increased from June 1984 to September 1984 in response to lower discharge brought about by decreases in velocity associated with increased macrophyte and algal density in channel A. Thus, an analysis of the first seven months of these data might be used to assess the response of periphyton to dissolved orthophosphate inputs at a concentration approximating the maximum concentration allowed for delivery waters to Everglades National Park under the 1984 Memorandum of Agreement.

Figure 24 presents six-week mean dissolved nitrate concentrations for experimental channel C from October 1983 to September 1984. Dissolved nitrate concentrations in experimental channel C varied during this time, responding to discharge and possibly biological activity.

As noted in channel B in experiment 1, there was a rapid uptake of dissolved orthophosphate in experimental channel A between the point of input and 95 m downstream (Figs. 25 and 26). The dissolved orthophosphate concentration in experimental channel A decreased from a mean of 28.6 $\mu g\ L^{-1}$ (as P) at 10 m to a mean of 13.4 $\mu g\ L^{-1}$ (as P) at 95 m, or by more than 53 percent over a distance of less than 100 m. While this uptake is substantial, it is not known if this rate of uptake could be sustained over a longer period of time or if the experimental channel would reach saturation, after which uptake capacity would be reduced. Unlike experiment 1, no significant ($P > 0.05$) uptake of dissolved nitrate was found to occur in experimental channel C between the point of introduction and 95 m downstream (Figs. 25 and 27).

A linear regression assessment of variability of dissolved nitrate and dissolved orthophosphate concentration among sites within the experimental channel (Figs. 26 and 27) indicated uptake of dissolved orthophosphate in experimental channel A ($P < 0.05$) but no significant uptake of dissolved nitrate in experimental channel C ($P > 0.05$). These results differ from experiment 1 where both dissolved orthophosphate and dissolved nitrate demonstrate significant between-site uptake in experimental channel B. These experiments suggest that trends in dissolved nitrate uptake only occurred when higher concentrations of dissolved orthophosphate were also introduced into the system.

An analysis of variance (ANOVA) indicated that there was a significant ($P < 0.001$) between-channel difference for both dissolved orthophosphate concentrations and total phosphorus concentrations between experimental channel A and experimental channel C, and between experimental channel A and the controls. There was also a significant ($P < 0.001$) between-channel difference for dissolved nitrate concentrations between experimental channel C and experimental channel A, and between experimental channel C and the controls (Table 6).

However, no significant ($P > 0.05$) between-channel difference was demonstrated for dissolved ammonia-nitrogen, dissolved organic nitrogen, or total nitrogen. An analysis of variance (ANOVA) of water chemistry data between sites within experimental channel A and within experimental channel C showed significant ($P < 0.05$) within channel differences for only dissolved orthophosphate in experimental channel A (Table 6).

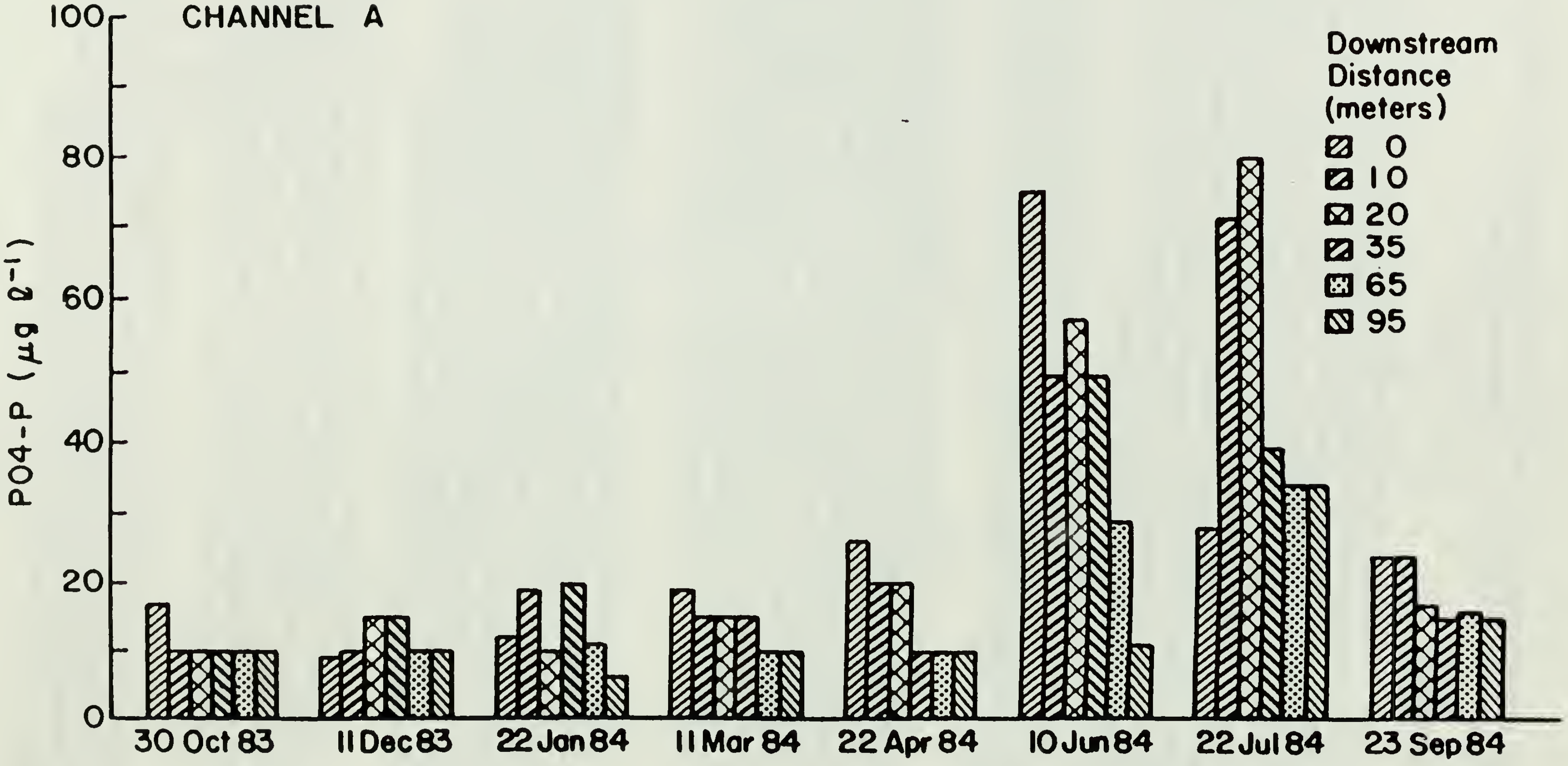


Figure 23. Six week mean dissolved orthophosphate (PO_4-P) concentrations (all sites) in experimental channel A.

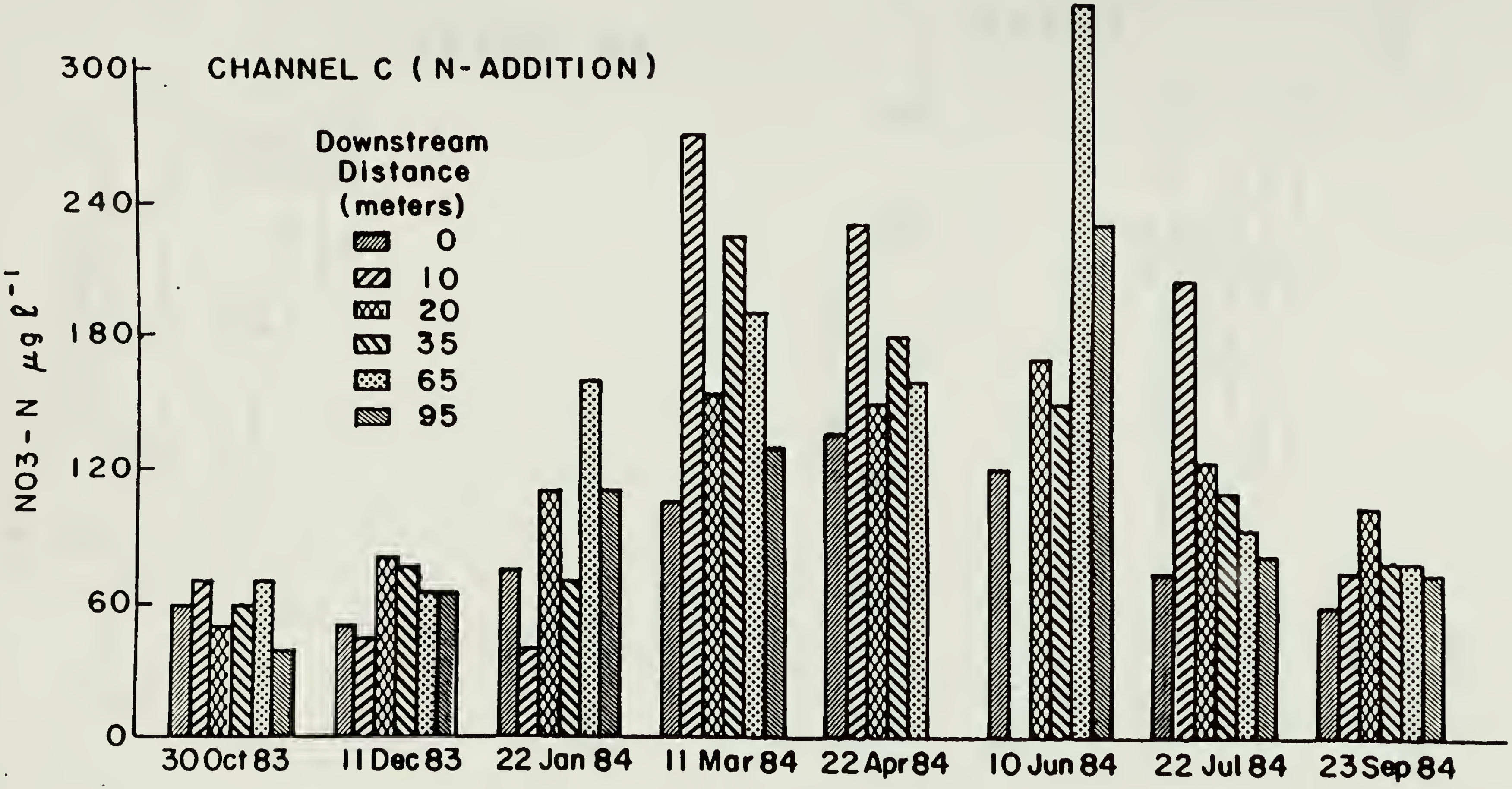


Figure 24. Six week mean dissolved nitrate (NO_3-N) concentrations (all sites) in experimental channel C.

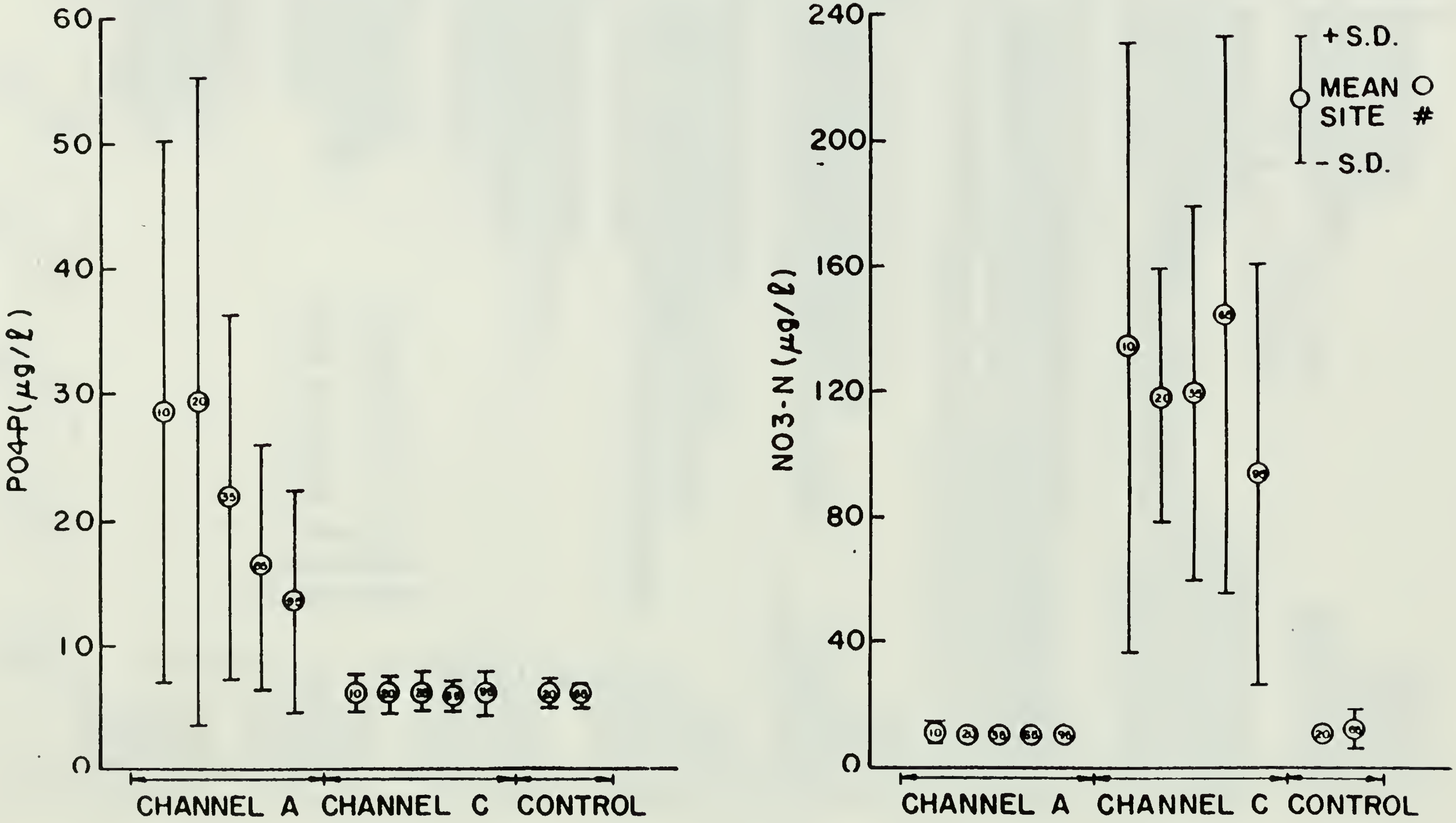


Figure 25. Mean concentration (by site) within experimental channel A, experimental channel C, and the controls for dissolved orthophosphate (n=11) and dissolved nitrate (n=8) (October 1983 - September 1984).

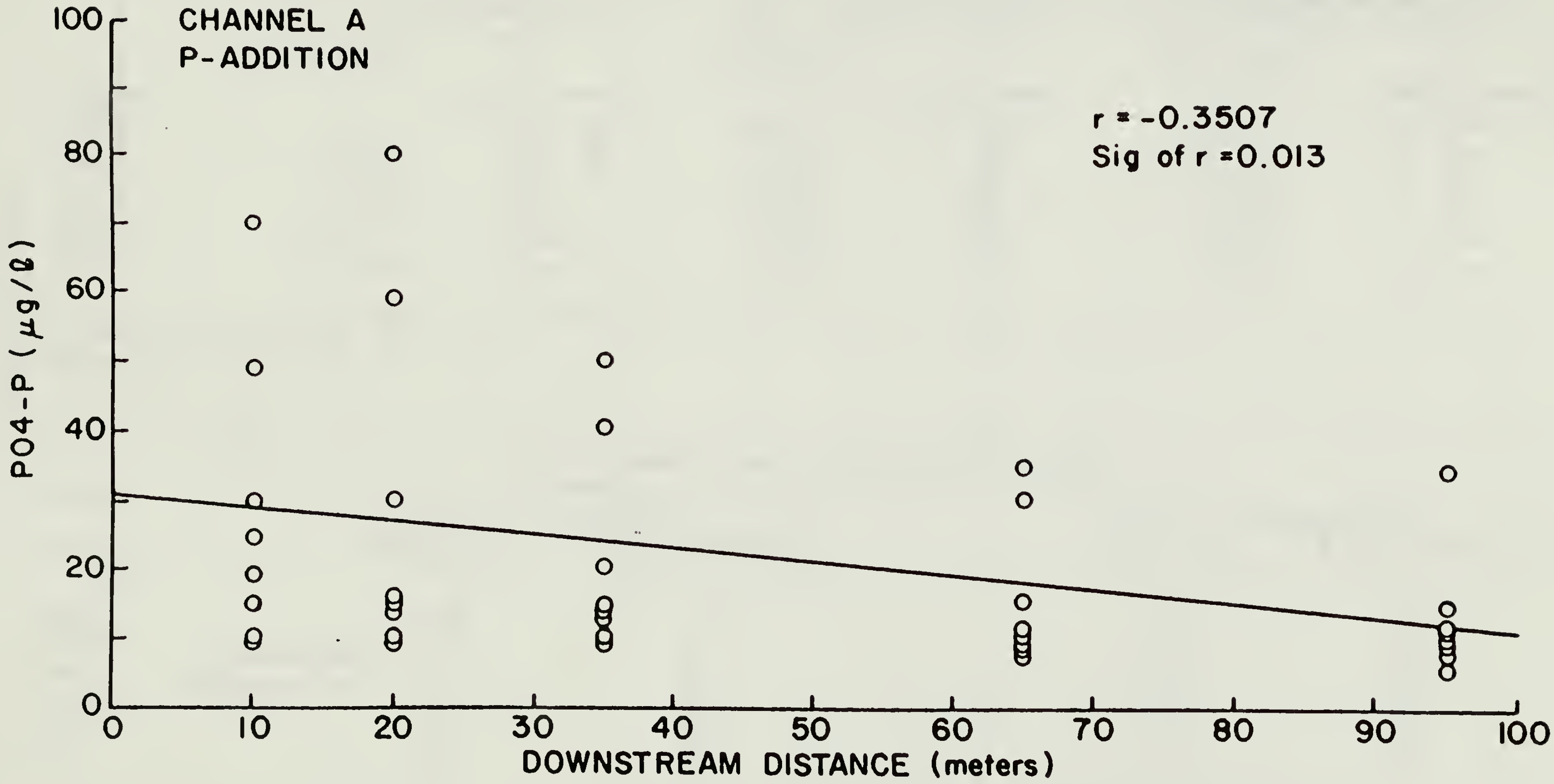


Figure 26. Change in dissolved orthophosphate concentration with distance in experimental channel A (October 1983 - September 1984).

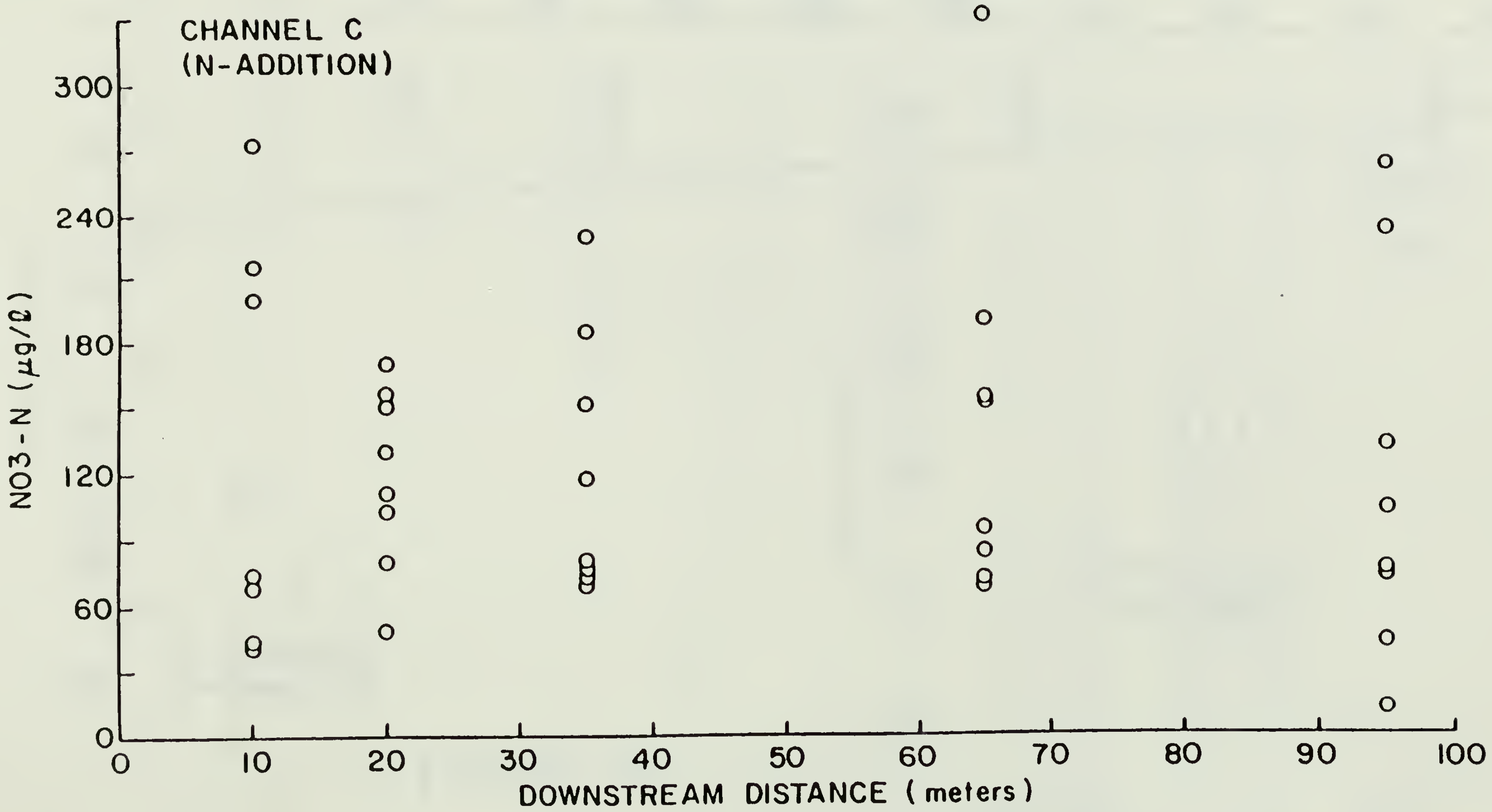


Figure 27. Change in dissolved nitrate concentration with distance in experimental channel C (October 1983 - September 1984).

Table 6. Results of between-channel and among sites within a channel analysis of variance (ANOVA) for experiment 2 water quality parameters.

EXPERIMENT 2: BETWEEN-CHANNEL ANOVA RESULTS

Parameter	Experimental Channel A vs. Control Channel		Experimental Channel C vs. Control Channel		Experimental Channel A vs. Experimental Channel C	
	Main Effect F	F Significance	Main Effect F	F Significance	Main Effect F	F Significance
NO_3-N	0.287	NS	166.615	***	128.989	***
NH_4-N	0.052	NS	0.100	NS	0.335	NS
ORG-N	0.204	NS	0.361	NS	0.672	NS
TN	0.191	NS	0.594	NS	0.669	NS
PO_4-P	24.256	***	0.133	NS	15.206	***
TP	10.237	***	0.254	NS	8.291	***

***Sig at 0.001 level
NS not Sig. ($P > 0.05$)

WITHIN-CHANNEL (AMONG SITES) ANOVA RESULTS

Parameter	Channel A		Channel C	
	Ratio (F)	Significance (F)	Ratio (F)	Significance (F)
NO_3-N	1.09	NS	1.98	NS
PO_4-P	3.57	*	1.09	NS
NH_4	1.73	NS	0.65	NS
ORG-N	1.51	NS	0.99	NS
TN	0.81	NS	0.78	NS
TP	1.82	NS	1.52	NS

* Sig. at 0.05 level
NS not sig. ($P > 0.05$)

Periphyton Biomass and Primary Production

The influence of dissolved orthophosphate only (channel A) and dissolved nitrate only (channel C) addition on periphyton biomass and primary production is presented in Figures 28-31 and in Table 7. In experimental channel A, mean periphyton biomass (chlorophyll *a* mean = 38.8 μg cm-2 wk-1; dry weight mean = 0.09 μg cm-2 wk-1) was approximately six to ten times greater than the mean periphyton biomass at the control sites (chlorophyll *a* mean = 3.8 μg cm-2 wk-1; dry weight mean = 0.015 μg cm-2 wk-1) as determined by both chlorophyll *a* concentration ($P < 0.01$) and dry weight ($P < 0.05$). Similarly, overall mean primary production at sites in experimental channel A (mean = 0.158 μg carbon fixed cm-2 hr-1) was five times greater than overall mean primary production at the control sites (mean = 0.031 μg carbon fixed cm-2 hr-1) when assessed on a per unit area basis. However, the mean primary production (i.e., the rate of primary production) on a per unit dry weight basis (which compensates for the increased biomass) did not differ significantly ($P > 0.05$) between the sites in experimental channel A (mean = 0.526 μg carbon fixed/μg dry weight) and the control sites (mean = 0.372 μg carbon fixed/μg dry weight).

Overall, the response of periphyton biomass and primary production in experimental channel A (dissolved orthophosphate only addition) was similar to that of experimental channel B (dissolved orthophosphate + dissolved nitrate addition) in experiment 1. Periphyton biomass and community structure responded rapidly, and while periphyton biomass and overall primary production increased, the rate of primary production (on a per gram biomass basis) remained the same. Changes in periphyton biomass occurred at dissolved orthophosphate concentrations allowable under present water quality standards. Concurrent changes in periphyton and macrophyte community composition are addressed in companion reports.

The changes induced by the dissolved nitrate only additions to experimental channel C were quite different than the changes that occurred in experimental channel A (dissolved orthophosphate only addition).

First, the evanescence of the periphyton mat, which occurred in experimental channel A within eight weeks of dissolved orthophosphate addition, were not noted in experimental channel C until after eight months of dissolved nitrate addition.

Second, the dramatic increase in periphyton biomass which occurred in response to nutrient addition in experimental channels A and B did not take place in experimental channel C. The mean chlorophyll *a* concentration of periphyton growing on glass slide artificial substrates in experimental channel A (mean = 38.8 μg cm^{-2} wk^{-1}) was significantly greater ($P < 0.001$) than the mean chlorophyll *a* concentration of periphyton grown in experimental channel C (mean = 2.8 μg cm^{-2} wk^{-1}). It was also found that the mean chlorophyll *a* concentration of periphyton on glass slides in experimental channel C (mean = 2.8 μg cm^{-2} wk^{-1}) was significantly less ($P < 0.05$) than the mean chlorophyll *a* concentration found on glass slides at the control sites (mean = 3.5 μg cm^{-2} wk^{-1}) (Fig. 31, Table 7). This indicates that excessive dissolved nitrate loading may cause growth inhibition in affected periphyton communities.

The mean dry weight of periphyton grown on the glass slide substrates in experimental channel A (mean = 0.09 μg cm^{-2} wk^{-1}) was also significantly greater ($P < 0.001$) than the mean dry weight of periphyton growing on the glass slides at sites in experimental channel C (mean = 0.01 μg cm^{-2} wk^{-1}). However, no significant difference ($P > 0.05$) was found between the mean dry weight determinations from sites in experimental channel C (mean = 0.01 μg cm^{-2} wk^{-1}) and the control sites (mean = 0.01 μg cm^{-2} wk^{-1}). It should be noted, however, that dry weight determinations in experimental channel C and the control sites were in a range near the limit of detecting meaningful differences, and at these low ranges the chlorophyll *a* measurements were found to be both more precise and more accurate than the dry weight determinations.

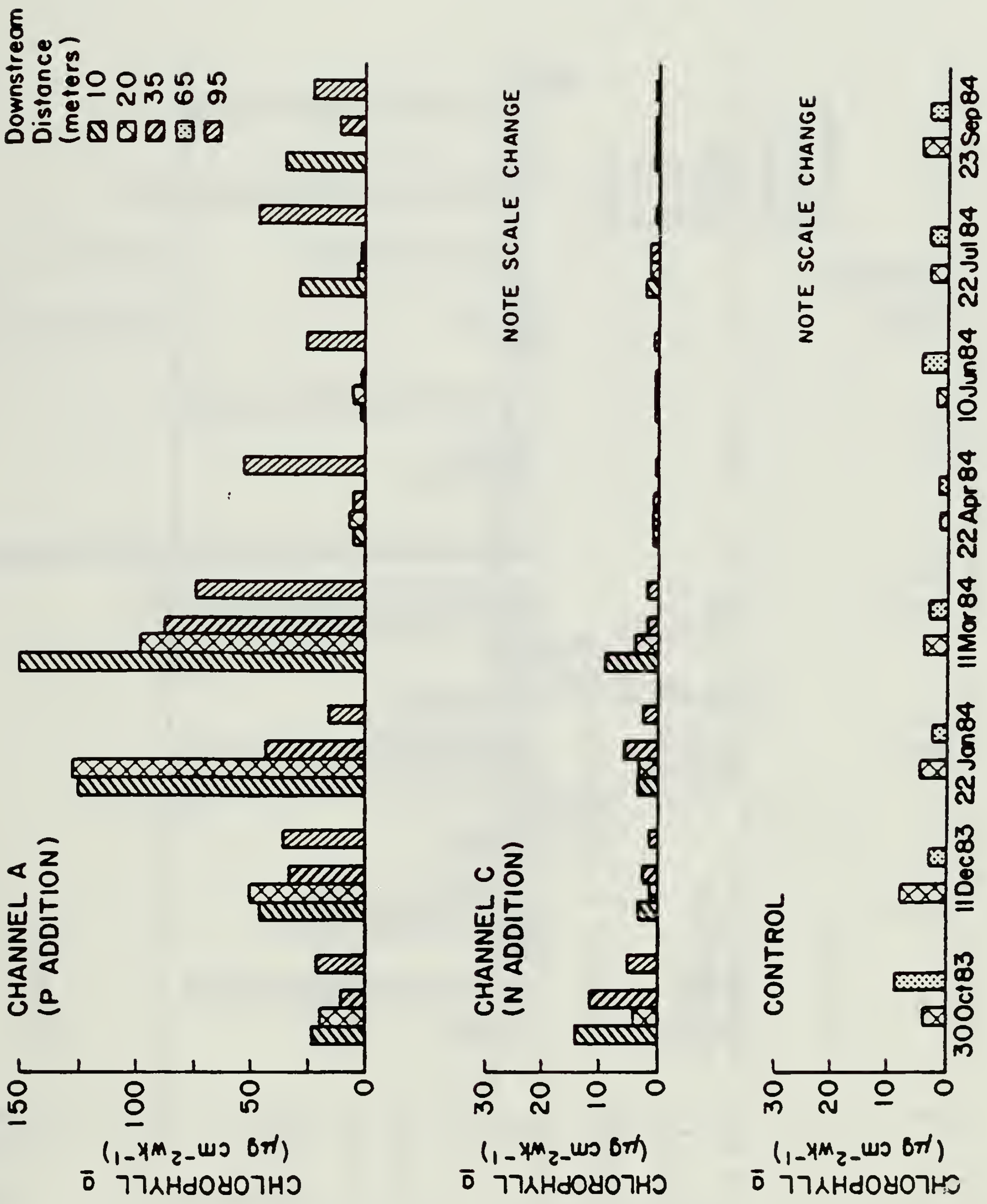
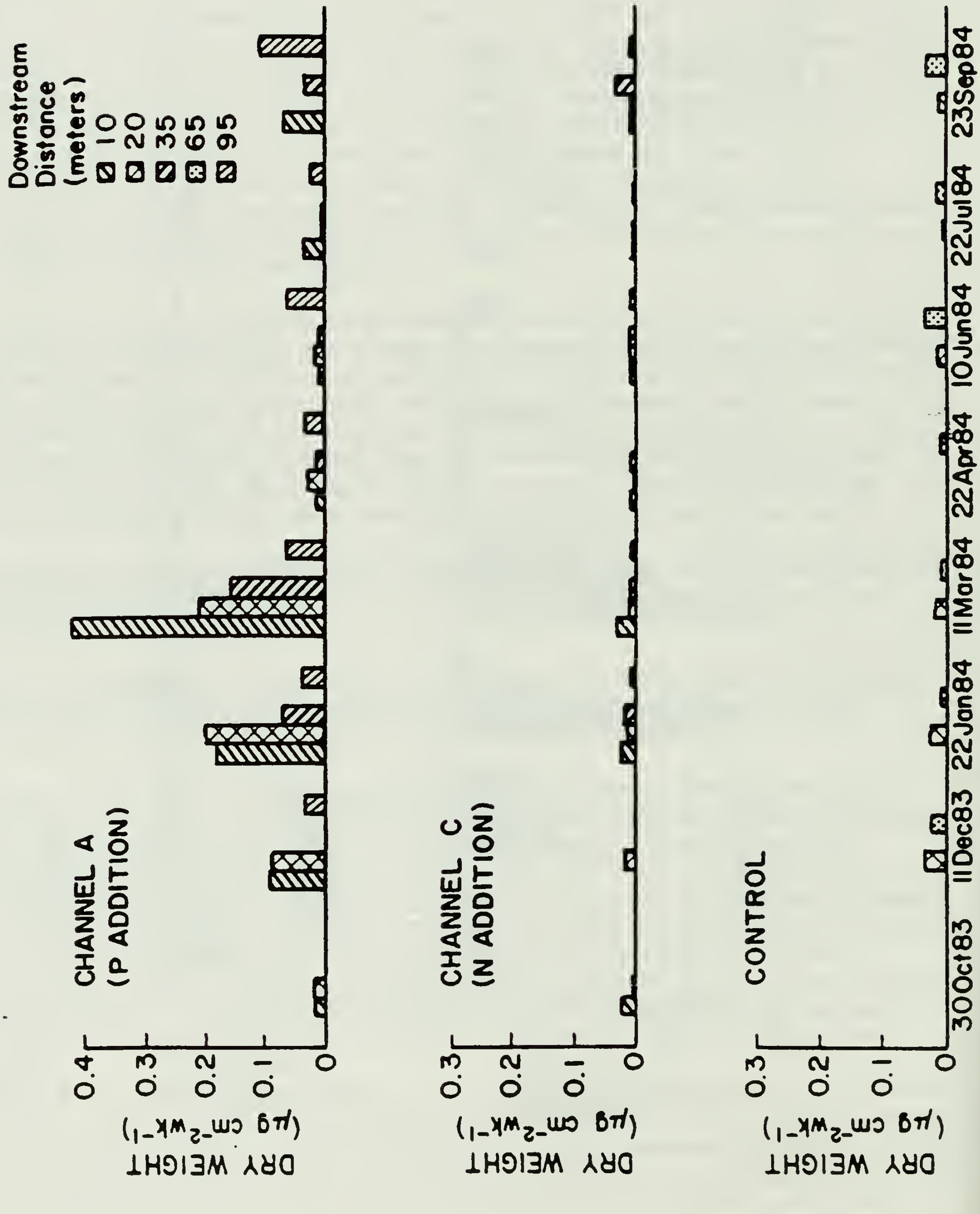


Figure 28. Chlorophyll *a* concentrations from periphytometers in experimental channels A and C and at the control sites.


CHANNEL A
(P ADDITION)
CHANNEL C
(N ADDITION)
CONTROL
DRY WEIGHT
(µg cm⁻²wk⁻¹)
0.4
0.3
0.2
0.1
0
Downstream
Distance
(meters)
10
20
35
65
95
30Oct83
11Dec83
22Jan84
11Mar84
22Apr84
10Jun84
22Jul84
23Sep84

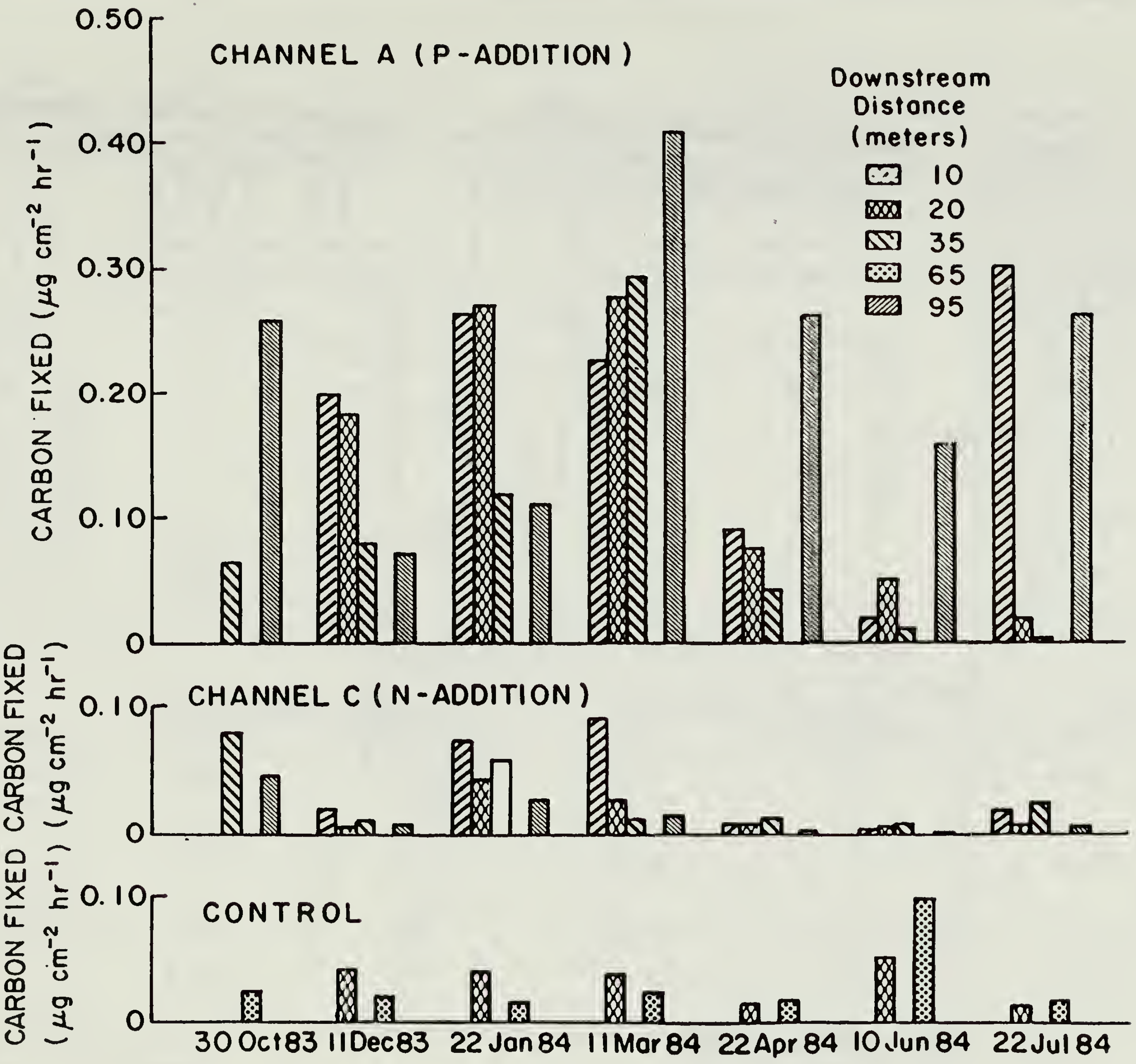


Figure 30. Primary production of periphyton from periphytometers located in experimental channels A and C and at the control sites.

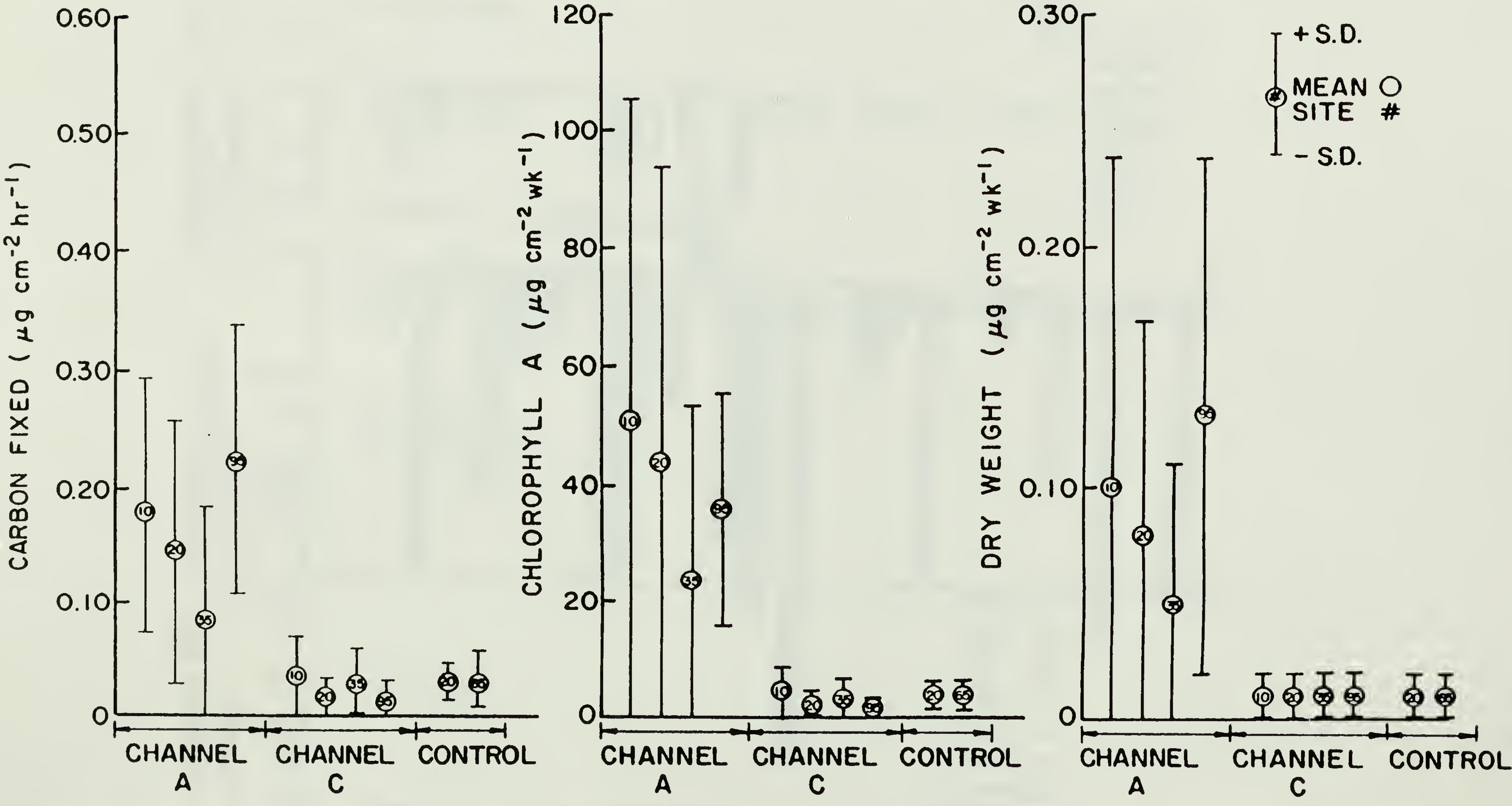


Figure 31. Summary of mean primary production and biomass data for experiment 2 (October 1983 - September 1984).

Table 7. Results of analysis of variance (ANOVA) between channels and among sites within a channel for experiment 2 biomass and primary production parameters.

BETWEEN-CHANNEL ANOVA RESULTS

	Experimental Channel A vs. Control Channel		Experimental Channel C vs. Control Channel		Channel A vs. Channel C	
Parameter	Main Effect F	F Significance	Main Effect F	F Significance	Main Effect F	F Significance
Carbon Fixed (per unit area)	1.542	NS	0.130	NS	0.533	NS
Carbon Fixed (per unit dry weight)						
Chla wk^{-1}	6.784	**	4.890	*	11.580	***
Dry wt wk^{-1}	3.650	*	1.875	NS	3.870	**

AMONG SITES WITHIN CHANNEL ANOVA RESULTS

	Experimental Channel A		Experimental Channel C		Control Channel	
Parameter	F	Significance	F	Significance	F	Significance
Carbon Fixed (per unit area)	1.98	NS	0.93	NS	0.04	NS
Carbon Fixed (per unit dry weight)	0.902	NS	0.313	NS	0.692	NS
Chla (cm^{-2} wk^{-1})	0.067	NS	0.786	NS	0.011	NS
Dry wt (cm^{-2} wk^{-1})	0.634	NS	0.712	NS	0.234	NS

*Sig at 0.05 level

**Sig at 0.01 level

***Sig at 0.001 level

NS not significant ($P > 0.05$)

Finally, it was found that while there was more overall primary production in experimental channel A due to the large increase of periphyton biomass, the rate of primary production (i.e., the primary productivity) on a carbon fixed per unit dry weight basis did not vary significantly ($P > 0.05$) among experimental channels A and C and the control sites. Also, differences among individual sites within experimental channels A and C and the control sites did not indicate significant variability for primary production, chlorophyll *a* concentration or dry weight.

DISCUSSION

The impetus to design and implement a field study to measure the response of the Everglades system to increased nutrient loading was generated by the desire of park management to know more about how changes in water quality that might arise from water management actions could affect the lower level of the food chain in Everglades National Park.

At the time of this study, a number of water management options, including the backpumping of water to enhance water supply in the Water Conservation Areas (SFWMD, 1982; SFWMD, 1984) and the southward release of nutrient-laden water from the Everglades Agricultural Area were being considered by water managers as possible responses to complex water management issues then affecting south Florida. In addition, Everglades National Park had proposed (Dr. Gary Hendrix, Everglades National Park, personal comm.) a number of operational and structural modifications in order to promote a more natural pattern of water delivery into the park.

While the extent to which these changes might affect the water quality in Everglades National Park was not known, a number of specific questions as to how key biological components might respond to increased nutrient loadings were posed. Initially, these questions were focused around: (1) the ability to the slough system to assimilate increased nutrient loading without a corresponding degradation of water quality; and (2) the changes that might occur in the natural periphyton and macrophyte communities in response to increased nutrient loadings.

In an attempt to find answers to these questions, dissolved orthophosphate and dissolved nitrate were added continuously to experimental channel B from April 1983 to September 1984. During this time period, dissolved orthophosphate concentration was increased to an average of 34.3 µg L-1 (as P), which is approximately six times the concentration found at the control sites (5.8 µg L-1 [as P]), and dissolved nitrate was increased to an average of 95.7 µg L-1 (as N), or approximately eight times the background level (11.2 µg L-1).

The effect of these additions upon the water chemistry of the slough system was measured by completing water chemistry determinations 10 m, 20 m, 35 m, 65 m, and 95 m downstream from the point of nutrient delivery. The results obtained indicated a rapid uptake of nutrients, over the 18-month duration of this study, with dissolved orthophosphate reduced from a mean concentration of 25.3 µg L^{-1} (as P) at 10 m to a mean concentration of 10.1 µg L^{-1} (as P) at 95 m. Similarly, dissolved nitrate decreased from a mean concentration of 62 µg L^{-1} (as N) at 10 m to a mean concentration of 29 µg L^{-1} (as N) at 95 m. While these data indicate that the slough system may assimilate dissolved orthophosphate and dissolved nitrate over the short-term (18 months), this assimilation is accompanied by major changes in the biological communities. In addition, the ability to continue net assimilation over the long-term is not known. Dolan et al. (1981) suggest that a long-term use of the marsh environment for phosphorus removal may be contingent upon the phosphorus adsorption capacity of the soil and the rate of peat production. Unfortunately, little information is available pertaining to the quantification of the overall inputs, outputs, and storages (both biotic and abiotic) of nutrients in a tropical marsh system such as the Shark River Slough. Such studies would be necessary to answer even basic questions about the ability of the slough system to retain or recycle nutrients.

The impact of dissolved orthophosphate + dissolved nitrate additions on the primary producers of the Shark River Slough was both rapid and dramatic. As noted earlier, the natural periphyton mat disappeared soon after the commencement of nutrient addition. Also, the mean biomass of the attached periphyton growing on the glass slide artificial substrates in experimental channel B increased approximately tenfold relative to the control sites, as measured by chlorophyll *a* concentration (15-fold increase), dry weight (13-fold increase), and overall primary production as measured by ^{14}carbon assimilation (ninefold increase on a per unit area basis). No significant differences ($P > 0.05$) could be detected for these parameters among the various sites within experimental channel B, indicating that the response of the periphyton to increased nutrient loading may be quite complex and not easily described as a direct function of nutrient concentration.

Overall, these data demonstrate that relatively modest increases in nutrient concentrations, even to levels currently allowed under the Memorandum of Agreement (1984), can significantly alter the natural periphyton community composition. The effects of periphyton community composition changes on higher levels of the food chain, on the geochemistry (e.g., the rate of peat and marl formation), or on the long-term water quality of the Everglades system are not known, but could be quite significant.

A second companion report (Walker et al., in prep.) discusses the effects of the increased dissolved orthophosphate and dissolved nitrate addition on the macrophyte population, including macrophyte biomass, community structure, and nutrient composition. It was found that after several months of nutrient addition, qualitative and quantitative changes in the macrophyte community were apparent.

The increased nutrient loading also affected bacterial activity, as measured by changes in the rate of cellulose decomposition. Maltby (1985) reports that cellulose decomposition significantly increased throughout the water column in response to dissolved orthophosphate plus dissolved nitrate addition in experimental channel B, with the greatest bacterial activity occurring near the water-sediment interface at locations closest to the point of nutrient addition.

A second experiment was conducted to determine if dissolved orthophosphate or dissolved nitrate acting alone could induce changes similar to those noted in experiment one. Experiment two was conducted from October 1983 to September 1984, during which time the mean dissolved orthophosphate concentration in experimental channel A was raised to 33.3 mg L-1 (as P), approximately six times the background concentration (5.8 mg L-1). Concurrently, the mean dissolved nitrate in experimental channel C was increased to 96.4 mg L-1 (as N), which is approximately nine times the background concentration (11.2 mg L-1 [as N]).

A rapid uptake of dissolved orthophosphate occurred in experimental channel A during experiment two. The mean dissolved orthophosphate concentration decreased from 28.6 µg L^{-1} (as P) at 10 m to 13.4 µg L^{-1} (as P) at 95 m. However, in contrast to experiment one, no significant ($P > 0.05$) uptake of dissolved nitrate occurred in experimental channel C as a consequence of the increased loading. As in experiment one, qualitative and quantitative changes in the biological components in the experimental channels became apparent soon after the commencement of the nutrient additions.

In experimental channel A (dissolved orthophosphate addition only), the periphyton mat dissipated within eight weeks, while the periphyton mat continued to remain in experimental channel C (dissolved nitrate addition only) until after eight months of nutrient addition. (The periphyton mat remained intact at the control sites during the duration of both experiments one and two.)

In experimental channel A, mean periphyton biomass increased significantly. Mean chlorophyll *a* concentration was 10 times greater than that at the control sites, mean dry weight increased sixfold relative to the control sites, and primary production as measured by ^{14}carbon assimilation was five times greater on a per unit area basis in experimental channel A than at the control sites.

Changes in both the macrophyte community and the rate of bacterial decomposition also occurred in experimental channel A. Walker et al. (in prep.) document changes in macrophyte community structure, while Maltby (1985) documents an increase in the rate of bacterial decomposition similar to that which occurred in experimental channel B.

The changes induced by the dissolved nitrate only additions in experimental channel C were quite different from the changes that occurred in response to dissolved orthophosphate only additions in experimental channel A. The dramatic increase in periphyton biomass that occurred in experimental channel A was not observed in experimental channel C. In fact, the mean chlorophyll *a* concentration in experimental channel C (2.8 $\mu g\ cm^{-2}\ wk^{-1}$) was significantly less ($P < 0.05$) than that reported for the control sites (3.5 $\mu g\ cm^{-2}\ wk^{-1}$). The mean dry weight and primary production of the periphyton grown on glass slide artificial substrates in experimental channel C did not differ significantly ($P > 0.05$) from those found at the control sites.

A response of the macrophyte community was also noted in experimental channel C, as documented in Walker et al. (in prep.). Unlike the dissolved orthophosphate-dosed experimental channels, there was not significant difference ($P > 0.05$) in the rate of bacterial decomposition between experimental channel C (dissolved nitrate addition only) and the control sites (Maltby, 1985).

The results obtained in experiment two suggest that, under natural conditions, phosphorus is the growth limiting nutrient for primary producers in the Shark River Slough ecosystem. Consequently, relatively minor increases in dissolved orthophosphate loading into the system cause biologically important changes in the lower levels of the food chain, thereby potentially affecting the natural functioning of the ecosystem.

Results obtained from experiment two further suggest that the addition of dissolved nitrate alone into the slough system does not promote the dramatic increase in periphyton biomass as seen with the dissolved orthophosphate additions. It was noted, however, that dissolved nitrate additions may cause some inhibition of growth, as the chlorophyll *a* concentrations in experimental channel C were less than those found in the controls. In addition, the natural periphyton mat also dissipated in response to dissolved nitrate addition, but only after eight months of dosing.

These results are not as conclusive as those documented for dissolved orthophosphate addition, but the possibility of some impact on the natural system appear to be supported by qualitative changes noted in the macrophyte community (Walker et al., in prep.) and algal species composition (unpubl. data).

CONCLUSIONS

These short-term field studies conducted in the Shark River Slough provide insight into the functioning of the natural wetlands in Everglades National Park. It would appear that the primary producers naturally found in the freshwater wetlands of the Shark River Slough are those species that have adapted to low nutrient conditions. These species, then, have a competitive advantage in a sub-tropical ecosystem characterized by high solar radiation, seasonal variability in inundation, and low nutrient input from rainfall and the upland watershed.

While it was found that the slough system has the ability, at least over the short-term, to function as an effective "filter" for the removal of some nutrient forms, this appears to be rapidly accompanied by major species shifts among the primary producers of the biological communities. The results of this study suggest that there is a high potential that long-term increases in the nutrient loading to Shark River Slough, would favor shifts to periphyton and macrophyte species that are more pollutant tolerant, and which can out-compete the natural assemblages of primary producers in an increased nutrient environment. These changes, in turn, could potentially alter higher levels of the ecosystem organization.

LITERATURE CITED

American Public Health Association. 1980. Standard methods for the examination of water and wastewater, Fifteenth edition. Published jointly with the American Water Works Association and Water Pollution Control Federation. Washington, D.C.

Brock, T. D. 1970. Photosynthesis by algal epiphytes of *Utricularia* in Everglades National Park. Bull. Mar. Sci., 20(4):952-956.

Brock, T. D., and M. L. Brock. 1967. Methodology for the measurement of chlorophyll, primary productivity, photophosphorylation and macro-molecules in benthic algae. Limnol. Oceanogr., 12:600-605.

Browder, J. A. 1982. Biomass and primary production of microphytes and macrophytes in periphyton habitats of the southern Everglades. South Florida Research Center Report T-662, Everglades National Park. Homestead, Florida.

CH2M HILL, 1978. Water quality studies in the Everglades Agricultural Area of Florida. Engineering report submitted to the Florida Sugar Cane League.

Davis, S. M. 1988. Sawgrass and cattail production in relation to nutrient supply in the Everglades. *In:* Freshwater Wetlands and Wildlife. Sharitz, R. R. and J. W. Gibbons (eds.), Office of Scientific and Technical Information, U. S. Department of Energy, Oak Ridge, Tennessee.

Dickson, K. G., A. C. Federico, and J. R. Lutz. 1978. Water quality in the Everglades Agricultural Area and its impact on Lake Okeechobee. Tech. Pub. 78-3, South Florida Water Management District, West Palm Beach, Florida.

Dolan, T. J., S. E. Bayley, J. Zoltek, Jr., and A. J. Hermann. 1981. Phosphorus dynamics of a Florida freshwater marsh receiving treated wastewater. J. of Applied Ecology, 18:205-219.

Federico, A. C., K. G. Dickson, C. R. Kratzer, and F. E. Davis. 1981. Lake Okeechobee water quality studies and eutrophication assessment. Tech. Pub. 81-2, South Florida Water Management District, West Palm Beach, Florida.

Federico, A. C., P. Millar, and F. Davis. *In prep.* Water quality and nutrient loading analysis of the Water Conservation Areas 1978-1983. South Florida Water Management District, West Palm Beach, Florida.

Flora, M. D., and P. C. Rosendahl. 1981. Specific conductance and ionic characteristics of the Shark River Slough, Everglades National Park, Florida. South Florida Research Center Report T-615, Everglades National Park, Homestead, Florida.

Flora, M. D., and P. C. Rosendahl. 1982a. An analysis of surface water nutrient concentrations in the Shark River Slough, 1972-1980. South Florida Research Center Report T-653, Everglades National Park, Homestead, Florida.

Flora, M. D., and P. C. Rosendahl. 1982b. The response of specific conductance to environmental conditions in the Everglades National Park, Florida. Water, Air and Soil Pollut. 17:51-59.

Flora, M. D., D. R. Walker, K. A. Burgess, D. J. Scheidt, and R. G. Rice. 1986. The response of experimental channels in Everglades National Park to increased nitrogen and phosphorus loading. Data Report: Chemistry and primary productivity. Water Resources Report 86-6. Water Resources Division, National Park Service, Fort Collins, Colorado.

Freiberger, H. J. 1972. Nutrient survey of surface waters in Southern Florida during a wet and a dry season, September, 1970 and March, 1971. U. S. Geological Survey, Open-File Report 72008. Tallahassee, Florida.

Gleason, P. J. 1974. Chemical quality of water in Conservation Area 2A and associated canals. Technical Publication 74-1. South Florida Water Management District. West Palm Beach, Florida.

Gleason, P. J., and W. Spackman, Jr. 1974. Calcareous periphyton and water chemistry in the Everglades. Pages 146-181 *in* P. J. Gleason (editor). Environments of South Florida: present and past. Miami Geological Society, Memoir II, Miami, Florida.

Lean, D. S., and B. K. Burnison. 1979. An evaluation of errors in the ^{14}C method of primary productivity measurement. Limnol. Oceanogr. 24:917-928.

Lew, R. M., M. D. Flora, and P. C. Rosendahl. 1982. An analysis of rainfall in Shark Slough. South Florida Research Center Report T-646, Everglades National Park. Homestead, Florida.

Loveless, C. M. 1959. A study of the vegetation of the Florida Everglades. Ecology 40:1-9.

Lutz, J. R. 1977. Water quality and nutrient loadings of the major inflows from the Everglades Agricultural Area to the Conservation Areas, Southeast Florida. Tech. Pub. 77-6, South Florida Water Management District, West Palm Beach, Florida.

Maltby, E. 1985. Effects of nutrient loadings on decomposition profiles in the water column and submerged peat in the Everglades. Pages 450-464 *in* Proceedings of a Symposium of the International Peat Society on Tropical Peat Resources-Prospects and Potential. International Peat Society, Helsinki, Finland.

Mattraw, H. C., Jr., D. J. Scheidt, and A. C. Federico. 1987. Analysis of trends in water quality data for Water Conservation Area 3A, the Everglades, FL. U. S. Geological Survey, Water Resources Investigations Report 87-4142. Tallahassee, Florida.

McPherson, B. F. 1973. Water quality in the conservation areas of the Central and Southern Florida Flood Control District, 1970-72. U. S. Geological Survey Open-File Report 73014. Tallahassee, Florida.

McPherson, B. F., B. G. Waller, and H. C. Mattraw. 1976. Nitrogen and phosphorous uptake in the Everglades Conservation Areas, Florida, with special reference to the effects of backpumping runoff. U. S. Geological Survey, Water Resources Investigations 76-29. Tallahassee, Florida.

Memorandum of Agreement (MOA). 1984. Memorandum of agreement among the Army Corps of Engineers, the South Florida Water Management District and the National Park Service for the purpose of protecting the quality of water entering Everglades National Park.

Millar, P. S. 1981. Water quality analysis in the Water Conservation Areas, 1978 and 1979. Technical Memorandum, Interim Progress Report, South Florida Water Management District, West Palm Beach, Florida.

Miller, W. L. 1975. Nutrient concentrations in southern Florida September, 1970 to April 1975. Open-File Report 75010. U. S. Geological Survey, Tallahassee, Florida.

National Oceanographic and Atmospheric Administration. 1983. Climatological data for Florida. Environmental Data Service. Asheville, N.C.

National Oceanographic and Atmospheric Administration. 1984. Climatological data for Florida. Environmental Data Service. Asheville, N.C.

Nichols, D. S. 1983. Capacity of natural wetlands to remove nutrients from wastewater. J. Water Pollut. Control Fed. 55(5):495-505.

Ornes, W. H., and K. K. Steward. 1973. Effects of phosphorus and potassium on phytoplankton populations in field enclosures. South Florida Environmental Project: Ecological Report No. DI-SFEP-74-07, U. S. Department of the Interior, Washington, D. C.

Rosendahl, P. C., and P. W. Rose. 1979. Water quality standards: Everglades National Park. Environmental Management 3(6):483-491.

Saunders, G. W., F. B. Trama, and R. W. Bachmann. 1962. Evaluation of a modified ^{14}C technique for estimation of photosynthesis in large lakes. Great Lakes Research Division Pub. #8, University of Michigan, Ann Arbor, Michigan.

Scheidt, D. J., D. R. Walker, R. G. Rice, and M. D. Flora. 1985. Diel dissolved oxygen levels under experimental nutrient loading conditions in the Shark River Slough, Everglades National Park (FL) (Abstract). Florida Scientist 48: Supplement 1.

Scheidt, D. J., M. D. Flora, and D. R. Walker. 1988. Water quality management for Everglades National Park *in* Lake Okeechobee Technical Advisory Council (LOTAC II) Interim Report to the Florida Legislature, Volume II. Presented at the Seventh International Symposium of the North American Lakes Management Society, November 4, 1987. Orlando, Florida.

South Florida Water Management District. 1982. An analysis of water supply backpumping for the lower east coast planning area. Special Report, South Florida Water Management District, West Palm Beach, Florida.

South Florida Water Management District. 1984. North New River backpumping water quality impact study - Report No. 1: Preconstruction and initial operation. Technical Memorandum, South Florida Water Management District, West Palm Beach, Florida.

Steward, K. K., and W. H. Ornes. 1975. Assessing a marsh environment for wastewater renovation. Water Pollut. Control Fed. 47:1880-1891.

Strickland, J. D. H., and T. R. Parsons. 1972. A practical handbook of seawater analysis. 2nd edition. Fish. Res. B. Can., Ottawa, Ontario.

Swift, D. R. 1981. Preliminary investigations of periphyton and water quality relationships in the Everglades Water Conservation Areas. Tech. Report 81-5. South Florida Water Management District, West Palm Beach, Florida.

Swift, D. R., and R. B. Nicholas. 1987. Periphyton and water quality relationships in the Everglades Water Conservation Areas 1978-1982. Technical Publication 87-2. South Florida Water Management District. West Palm Beach, Florida.

United States Geological Survey. 1979. Methods for determination of inorganic substances in water and fluvial sediments. Techniques of Water Resources Investigations of the United States Geological Survey. U. S. Government Printing Office, Washington, D. C.

Van Meter, N. N. 1965. Some quantitative and qualitative aspects of periphyton in the Everglades. M.S. thesis, University of Miami, Coral Gables, Florida.

Van Meter-Kasinof, N. N. 1973. Ecology of the microalgae of the Florida Everglades: Part I. Environment and some aspects of freshwater periphyton, 1959-1963. Nova Hedwigia, 24:619-664.

Walker, D. R., M. D. Flora, R. G. Rice, and D. J. Scheidt. *In prep.* The response of experimental channels in Everglades National Park to increased nitrogen and phosphorus loading - Part II: Macrophyte community structure and chemical composition. South Florida Research Center, Everglades National Park, Homestead, Florida.

Waller, B. G. 1975. Distribution of nitrogen and phosphorous in the conservation areas in South Florida from July, 1972 to June, 1973. U. S. Geological Survey, Water Resources Investigations 5-75. Tallahassee, Florida.

Waller, B. G., and J. E. Earle. 1975. Chemical and biological quality of water in part of the Everglades, Southeastern Florida. U. S. Geological Survey, Water Resources Investigations 56-75. Tallahassee, Florida.

Wilson, S. U. 1974. Metabolism and biology of a blue-green algal mat. M.S. thesis, University of Miami, Coral Gables, Florida.

Wood, E., J. Ferguson, and N. G. Maynard. 1974. Ecology of the micro-algae of the Florida Everglades. Pages 123-145 *in* P J. Gleason (editor). Environments of South Florida: present and past. Miami Geological Society, Memoir II, Miami, Florida.